KEMBLE WIDMER

The Geology and Geography of New Jersey

THE NEW JERSEY HISTORICAL SERIES

$3.95

ONE of the most absorbing riddles man has ever tried to solve is what forces formed our earth. How different was the area now known as New Jersey a million years ago, fifty million, a hundred million, five hundred million years ago?

Dr. Widmer provides the answers in this book as he begins by explaining the interrelationships of three geologic concepts. The first of these are the materials involved: rocks and minerals. Next are the processes: the building up and eroding of the earth's surface. Finally the time factor appears. He notes the importance of understanding geologic time (where eras, periods, and epochs take the place of days, hours, and minutes) and shows that in New Jersey there are three convenient points of reference for keeping geologic time in proper perspective: Precambrian, Triassic, and Pleistocene.

With the fundamentals of geology explained, he proceeds to discuss the four general regions—or physiographic provinces—of which the state is composed, showing how geography is affected by geology. The Highlands, formed in the Precambrian period more than 600 million years ago, contain the oldest rocks found in New Jersey. The mineral resources discovered here have forced the development of roads, canals and railroads through this barrier to westward movement. In addition, the world famous Franklin zinc deposits and the iron mines so important to New Jersey's early economy are to be found in the Highland ranges.

Formation of the Ridge and Valley region spans some 300 million years. The area is rich in the geologic variation and the story of the development of life which is found in the Paleozoic Era. The central and most populated part of the state was formed about 200 million years ago during Triassic times, and is known as the Piedmont. The fourth and largest general area is the Coastal Plain, which began forming more than 100 million years ago during the time of the ad-

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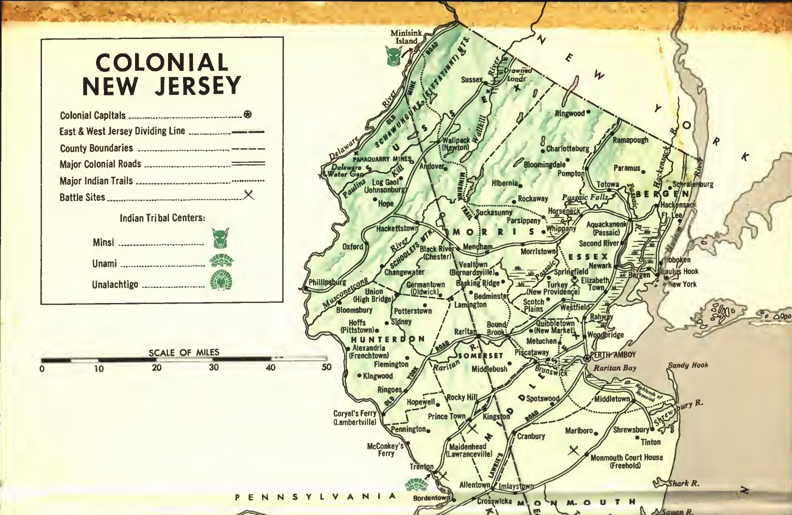
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County Boundaries
Major Colonial Roads
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Battle Sites
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Minisink Island
Drowned Lands
Sussex
Wallpack (Newton)
Andover
Delaware River
Delaware Water Gap
PAHAQUARRY MINES
OLD SCHAWUNGUNK (KITTATINNY) MTS.
OLD MINE ROAD
MINISINK TRAIL
Wallkill
Paulins Kill
Log Gaol (Johnsonburg)
Hope
Ringwood
Charlotteburg
Bloomingdale
Pompton
Ramapough
Paramus
Totowa
Passaic Falls
Passaic R.
Hackensack River
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Schralenburg
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Ft. Lee
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Second River
Hackettstown
Oxford
Phillipsburg
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SCHOOLEYS MTN.
Black River (Chester)
Mendham
Morristown
Newark
Bergen
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Changewater
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Basking Ridge
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Middlebush
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OLD YORK ROAD
Ringoes
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Prince Town
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ROAD
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Marlboro
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McConkey's Ferry
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Monmouth Court House (Freehold)
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Mount Holly
Moorestown
Rancocas R.
Ayrstown
Ongs
Philadelphia
Cooper's Ferry (Camden)
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Gloucester
FT. NASSAU
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Woodbury
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Raccoon Cr.
Brotherton
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Quinton
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Little Egg Harbor
Brigantine Beach
Absecon Beach
Great Egg Harbor
Peck's Beach
Ludley's Beach
7 Mile Beach
5 Mile Beach
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The Geology and Geography of New Jersey

THE NEW JERSEY HISTORICAL SERIES

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Volume 19

The New Jersey Historical Series

The Geology and Geography of New Jersey

KEMBLE WIDMER

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FOREWORD

Many tracks will be left by the New Jersey Tercentenary celebration, but few will be larger than those made by the New Jersey Historical Series. The Series is a monumental publishing project—the product of a remarkable collaborative effort between public and private enterprise.

New Jersey has needed a series of books about itself. The 300th anniversary of the State is a fitting time to publish such a series. It is to the credit of the State's Tercentenary Commission that this series has been created.

In an enterprise of such scope, there must be many contributors. Each of these must give considerably of himself if the enterprise is to succeed. The New Jersey Historical Series, the most ambitious publishing venture ever undertaken about a state, was conceived by a committee of Jerseymen—Julian P. Boyd, Wesley Frank Craven, John T. Cunningham, David S. Davies, and Richard P. McCormick. Not only did these men outline the need for such an historic venture; they also aided in the selection of the editors of the series.

Both jobs were well done. The volumes speak for themselves. The devoted and scholarly services of Richard M. Huber and Wheaton J. Lane, the editors, are a part of every book in the series. The editors have been aided in their work by two fine assistants, Elizabeth Jackson Holland and Bertha DeGraw Miller.

To D. Van Nostrand Company, Inc. my special thanks for recognizing New Jersey's need and for bringing their skills and publishing wisdom to bear upon the printing and distributing of the New Jersey Historical Series.

My final and most heartfelt thanks must go to Kemble Widmer, who accepted my invitation to write *The Geology and Geography of New Jersey,* doing so at great personal sacrifice and without thought of material gain. We are richer by his scholarship. We welcome this important contribution to an understanding of our State.

RICHARD J. HUGHES
Governor of the
State of New Jersey

January, 1964

PREFACE

Within the small area of New Jersey there is probably more geology and more opportunity to demonstrate geologic concepts than can be found in most areas of our globe. The peninsula of New Jersey between the Hudson and Delaware Rivers is a transition area between the geology of New England and New York, to the north and east, and the mid-Atlantic and Coastal Plain states to the south and west. New Jersey's geology is such that the State is used as an outdoor laboratory by many of the geology departments of our universities.

The great variety of New Jersey's landscape is unknown to most of our visitors and many of our citizens. There is another large group of citizens throughout the world who would know a great deal about the zinc mines at Franklin or about the zeolite minerals, without knowing anything about the geology of the State. Franklin and the New Jersey trap rocks have a special meaning to mineralogists. Minerals collected from these localities in New Jersey are on display in most of the major museums of the world. It is the hope of every mineralogist that before he dies he will have an opportunity to visit and collect minerals at Franklin.

This interest in New Jersey geology has been no passing fancy. After new concepts have developed in areas of more simple relationships, they have been restudied in the more complicated New Jersey geology to determine the effect of multiple or transition effects. The first summary of the Geology of New Jersey, and the first geologic map of the State was published by George H. Cook in

1868, less than a quarter century after the organization of the first of the national surveys, and less than a century after the first presentation of the Philosophy of Natural Order which we now call geology.

The Tercentenary year of the State is the Centennial year of the New Jersey Geological Survey which is now the second oldest, from the point of view of continuous operation, of the State Surveys. Actually the New Jersey Geological Survey was in operation from 1835 to 1840, and from 1854 to 1855. As the science of geology grew in the United States, New Jersey became an important locality in the development of many geologic concepts. The mineral occurrence at Franklin has been a constant stimulus in the development of mineralogy. In the concepts of Pleistocene geology the Jerseyan glaciation and many of the basic studies of the effects of continental glaciation were begun in the State. The Cretaceous Faunas, the Floras of the Raritan Formation, and the occurrence of the Greensand Marl have all triggered more extensive investigation in stratigraphy and paleontology, first within New Jersey, and then outside its borders.

The degree of interest in the geology and geography of New Jersey and the need for this publication are demonstrated by the rapidity with which bulletins on the geology of New Jersey and geologic maps of the State have always been sold.

This book could not have been written without the assistance, advice, and cooperation of many of my professional colleagues, and my friends among the many mineral societies in New Jersey. Discussions with Professor Erling Dorf, Geology Department, Princeton University, and Edward W. Zukaukas, M.D. of Moorestown, were particularly helpful. The co-editors of this series, Dr. Wheaton J. Lane, and Dr. Richard M. Huber were most helpful in establishing the plan of presentation and in monitoring the writing for the exclusion of technical jargon.

John L. Baum, Geologist for the New Jersey Zinc Company, critically reviewed the Pre-Cambrian chapter.

Guido Weigend, Rutgers University critically reviewed the chapter on geography. Their assistance and their detailed criticism is greatly appreciated. I am most appreciative of the comments and suggestions of John Cunningham, of James Yolton, Upsala College, of Sheldon Judson, and John Maxwell, Princeton University, Frank S. Kelland, Montclair State College, and Marylin C. Kelland, Newark State College, who served as critical readers. The author will take full responsibility for any errors which have slipped by the readers and editors.

Staff of the New Jersey State Museum and geologists of the Bureau of Geology, have been particularly helpful in searching picture files, and summarizing detailed information on specialized topics. The time devoted to these efforts and their discrimination in the selection of material supplied is appreciated.

Thanks is due the members of my family for enduring my ill-temper and absent-mindedness, while absorbed in writing. I am grateful for the patience shown by the secretarial staff and draftsmen of the Survey for the stenographic help during the numerous re-writings and re-castings of some of the more involved parts of the text, and in the preparation of the plates. I am sure that family, fellow-workers, and colleagues will be glad that this has been completed. It is hoped that this book has been written in a way which will permit the interested amateur to understand the complexities of the geology and geography of New Jersey, without getting lost in the technical details of these two sciences.

Kemble Widmer

Pennington, New Jersey
September, 1964

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A FRAME OF REFERENCE

GEOLOGY IS ALWAYS underfoot and taken for granted by most of us. It is one of the few sciences generally concerned with conditions which cannot be reproduced in a laboratory. The concepts of geology are based, therefore, upon observation, logical deduction, and "detective work" rather than upon experimentation, classification, precise measurements and the establishment of mathematical rules or formulae. Many modern geologists are seeking to establish qualitative and quantitative values for the geologic processes which the early workers recognized as a result of their diligent field work and keen observation. The methods of physics and chemistry are providing valuable tools for geologists seeking to discover new mineral deposits or new understanding of nature's secrets.

Geology is basic to many sciences. The origin of our planet is a major problem in astronomy and geology. Knowledge of the evolution and extinction of life forms is fundamental to understanding biology. The wider range of values for compositions, temperatures, and pressures encountered in the study of the formation of igneous rocks present the investigator of the subject with many conditions requiring a detailed knowledge of both physics and chemistry. Above all, an understanding of geology gives one a sense of time, of the infinite, of the force and majesty of nature which makes one aware of the insignificance of the individual in such a complex and wonderful system.

For most of us, the geologic processes are so gradual and work so slowly that we see no change. It is easy to think in terms of the "everlasting rocks and the eternal hills." Yet the student of geology knows that the rocks composing the world's highest mountains were formed beneath the sea in relatively recent geologic time. He also knows that no part of the original crust of the earth remains because the oldest known rock is made of mineral fragments of still older rocks—situations which are hardly indicative of "everlasting rocks and the eternal hills."

Geology, in essence, is composed of the interrelationships of three sets of terms and concepts: materials, processes, and time. Rocks and minerals are the materials upon which the geologic processes act through geologic time. In geology, there is plenty of time. The processes, acting so slowly that we can hardly observe the changes, can finally level the highest mountains and, in so doing, pile thousands upon thousands of feet of sand and mud as debris from the continents into the margins of the ocean basins.

A mineral is a naturally occurring inorganic substance with definite physical properties; a fixed chemical composition; or a fixed range of chemical compositions and usually has a definite crystal structure. There are about two thousand species and varieties but only about twelve minerals (quartz, plagioclase feldspar, orthoclase feldspar, amphibole, pyroxene, olivine, mica, calcite, hematite, limonite, dolomite, and the clay minerals) are found as the sole or major constituents of the most common rocks.

A rock is an aggregate of one or more minerals. The same mineral or minerals may make up more than one rock type. Thus calcite, in submicroscopic grains, is the principal mineral in limestone and in a recrystallized form in marble. Quartz may be the only constitutent of sand, sandstone, or quartzite. The same group of minerals (plagioclase feldspar, pyroxene, and lesser quantities of the same accessory minerals) may form basalt or gabbro. At the other extreme in classification may be a rock

called a conglomerate made up of many fragments of minerals and rocks.

All rocks fall into one of the three great classes: igneous (formed from molten silicate melts), sedimentary (formed from the fragments or precipitates resulting from the breaking down of other rocks by weathering), or metamorphic (resulting from the recrystallization or reconstitution of a rock by heat or pressure or both due to geologic forces acting in the crust of the earth).

In New Jersey, we have one of the three localities in the world where more than two hundred minerals have been found in a very small area. Some thirty minerals were first found in Sussex County at Franklin, and of these several have never been found elsewhere. With respect to rocks, New Jersey has more than sixty mapable units and probably several additional types and varieties. There are, however, a number of major rock types found in abundance elsewhere in the world which are not found in New Jersey. On the other hand New Jersey is the United States' leading producer of two rocks, diabase and greensand marl, also sometimes called mineral commodities. When one thinks of ore, one usually thinks of the minerals which yield gold, silver, iron, copper, or some other metal. The best definition is: *an ore is any rock or mineral which can be extracted at a profit.* With such a definition, New Jersey produces a most unusual variety of ores and occupies a unique position as the sole producer of two and a leading producer of five in the mineral economy of our country.

The geologic processes, which act on the above-mentioned geologic materials, can be divided into two groups: those that tend to erode, lower, or destroy the continental land masses; and those that, by acting deep within the crust, tend to counteract these forces by raising or building up the continental masses. The major forces of erosion are: stream erosion which acts on all lands everywhere; shore-line erosion which acts on the edges of the continents and on the shores of lakes and ponds; continental glaciation which has acted on large

areas of the continents in the higher latitudes; mountain glaciation, a more restricted area of erosion by ice in the higher altitudes; and wind erosion—perhaps the most unusual and restricted of the major types of erosion processes acting on dry loose sediments chiefly in deserts or along shore lines or river valleys. In New Jersey's geologic history, each of these processes has been a dominant one in a large part of the state at one time or another with only one exception, mountain glaciation. There is no evidence that mountain glaciation has ever taken place in New Jersey, but it probably took place for a short time in the late Pleistocene, in the Catskill Mountains of New York, just a few miles north of the New Jersey–New York border.

Isostatic uplift, the vertical movements of the crust, and orogenic movements or the compressive movements of the crust which cause folding of rock masses, tend to bring large masses of rock above the level of the oceans and counteract the processes of erosion. Both types of crustal adjustments have taken place in New Jersey, although many of the crustal movements in New Jersey would seem to have been more of a tilt than the simple vertical movement or isostatic uplift so well exemplified by the Grand Canyon region of Arizona. All the complexities of the orogenic movements or folding of rocks are nicely demonstrated by the Paleozoic rocks of northern New Jersey particularly in Sussex and Warren counties.

Associated with movements of the crust of the earth are the phenomena of earthquakes and vulcanism. Earthquakes occur as the various bodies of rock move in yielding to internal pressures. As a result of the heat and pressure of these crustal forces rock materials may become molten and reach the surface to spew forth in volcanic activity. As erosion and crustal movements continue over the eons of geologic time, masses of rock which solidified at the "roots" of the mountains deep within the crust during earlier orogenic movements may be exposed at

the surface as granite batholiths, diabase sills, or other kinds of intrusive igneous rock bodies.

Of all the geologic names with those tongue-twisting pronunciations and obscure origins, none are quite so discouraging to the beginner as the names for geologic time. They seem to have no rhyme nor reason and yet, with a few memory aids, they are not too difficult to learn and keep in proper order. To the geologist, the time-terms are indispensable and have greater meaning and scope than one realizes. Eventually, for each time-term the geologist will not only associate a chronological value in approximate millions of years and a position in the whole sweep of geologic time but also will associate with it certain fossils, rock types, formations, economic products, climates, geologic events, and areas of the world. To a New Jersey geologist, "Triassic" should evoke such thoughts as 45 million years long; 225 million years ago; certain types of early dinosaur and primitive plants; red shale and basalt lavas; the Newark series of rocks; "trap rock" and "brownstone"; deserts and playa lakes in deep valleys with volcanoes along their edges; and the geographic areas of central New Jersey, the Connecticut Valley, Nova Scotia, and the Piedmont of Pennsylvania, Maryland, and Virginia. He might then also think of the Trias of Germany, the area from which the name is derived, with its distinctive outcroppings of red sandstones. He may also think of areas such as the Grand Canyon where there are spectacular exposures of rocks formed in the Triassic period.

The various divisions of geologic time are not necessarily of equal length. The largest divisions, "Eras," end in *zoic,* with "Paleozoic" meaning dawn of life, "Mesozoic" meaning middle life (and this is in the middle of the time scale), and "Cenozoic" meaning recent life.

The eras are divided into periods. The first, or earliest, of the Paleozoic periods is the Cambrian, named for the rocks in southern Wales or Cambria. Cambrian rocks are the first to have abundant fossils and although there are

geologic eras and other time-terms for the non-fossiliferous rocks of the Precambrian times it is convenient to designate all time more than 600 million years ago with the time-term Precambrian.

The Cenozoic is still divided into two periods, Tertiary and Quaternary, names left over from the very early days of setting up a geologic time scale—most Paleozoic rocks on this scale were called secondary and the Precambrian rocks were in the primary division.

Periods are divided into epochs. In the Cenozoic, because the various sequences of rock contain many fossils of animals which are still living or have closely related living representatives, the formations are usually discussed with reference to the epoch during which they were deposited. The epochs of the Cenozoic begin with the Paleocene (not found at the surface in New Jersey) and end with the Pleistocene and Recent of the Quaternary period.

In New Jersey there are three convenient reference points for keeping geologic time in proper perspective. The first of these is the Precambrian in which all rocks are more than 600 million years old. Nearly all the rocks of this age are found in the New Jersey Highlands. The second reference point is the Triassic—the central and most populated part of the state—which began about 225 million years ago. The Pleistocene, or Ice Ages, an epoch of the Quaternary period of the Cenozoic era which began about a million years ago is the third reference point. Some geologists, including the writer, feel that we are still in the Pleistocene. The term "Recent," the youngest of the geologic epochs, is no longer a useful time-term. "Recent" was defined as the time since the first appearance of man, and man's existence on the scene is now known to date from early or slightly pre-Pleistocene times.

Only four geologic periods are not represented by rocks found in New Jersey. The Mississippian, Pennsylvanian, and Permian of the late or upper Paleozoic are

found in Pennsylvania west or northwest of New Jersey. Rocks of Jurassic age are not found in eastern North America, although some of the early geologic authors on New Jersey thought our Triassic rocks might be, in part, of Jurassic age.

Wherever we go in the world we will most often see sedimentary rocks. They form a veneer up to 20,000 feet or so in thickness upon the igneous rocks which form 95 per cent of the crust. A mapable rock unit is usually a formation. In New Jersey nearly thirty-five different sedimentary formations (loose sand, gravel, or clay) or sedimentary rock formations (lithified material) cover more than four-fifths of New Jersey. Many contain fossils and all have been deposited in beds or strata.

The relationships of these strata to each other and the changes and events in geologic time which they indicate are called stratigraphy. A detailed study of the contained fossils, the mineral grains, and the arrangement of the constituents provides clues as to the origin of the sediments. The composite diagram giving the thickness and characteristics of sequences of rocks is called a stratigraphic column.

Historical geology uses the succession of strata to develop the history of the changes in climate, topography, and life in the geologic past. As part of these events, the strata may have been folded, tilted, or broken. The study of the arrangement of strata, is called structural geology. Northern New Jersey has complexly folded and broken Paleozoic rocks. The Triassic rocks of central New Jersey have a general northwesterly inclination or dip with several major breaks or faults and both intrusive and extrusive igneous rocks. The sediments of the southern New Jersey Coastal Plain have only a very slight southeasterly tilt, and are usually not consolidated or cemented into what we normally think of as rock.

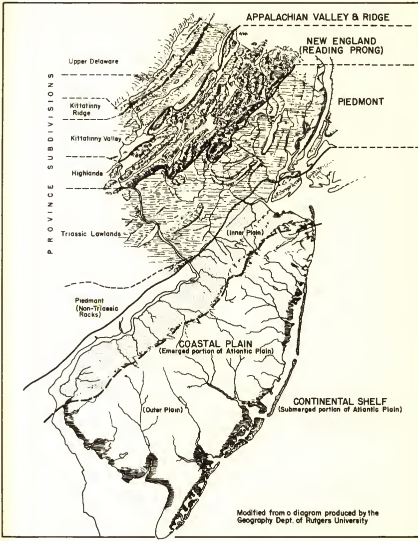
When rocks break without displacement, and all rocks break eventually, the breaks are known as joints. Such breaks are significant in helping to determine the degree

and rapidity of weathering and/or erosion. The rapidity of weathering in turn influences the development of the topography of an area.

When a movement of one side of a break in the rock takes place with respect to the other side, the break or joint becomes a fault. When this type of break and movement takes place, there may be a noticeable earthquake. Movements deep within the crust by metamorphism or rock flowage may or may not take place without any such surface manifestation of the movement. There are many kinds of faults and they are highly significant in the development and in the study of geologic structures.

Faults are to most students of geology one of the more interesting of the geologic phenomena. Perhaps this is because it is difficult for the average person to conceive of rock masses moving such great distances along such a narrow zone of broken rock and area of movement. One of the Triassic border faults extends in a nearly straight line from Boonton some thirty-four miles to and beyond the Hudson River. Along this segment of the border fault a thickness of several thousand feet of Triassic sandstones is downdropped into contact with the adjacent Precambrian gneisses of the Highlands. The zone of crushed rock in the fault may be a few inches thick or a hundred feet wide and although the fault had been mapped for more than sixty years, it had never actually been seen in an exposure until 1955 when an excavation was made on the fault. A study of the geologic records in the New Jersey Geological Survey office turned up a geologic note, however, which stated that an attempt had been made in the 1890's to mine material which looked like coal at a location north of Boonton in the valley occupied by the border fault. The mine naturally wasn't successful because the "coal" wouldn't burn.

It would be logical to assume that in an area where the rocks, geologic structures, and geologic history are the same, that the topography at the present time would have a characteristic pattern quite different from adja-



PHYSIOGRAPHIC PROVINCES OF NEW JERSEY
From a diagram produced by the Geography Department of Rutgers University

cent areas where there was a different set of rocks, structures, and geologic history. Such is the usual case and it is particularly well illustrated in New Jersey where there are four different natural areas or regions. Each area in New Jersey is a part of a much larger region of similar topography which also is found in adjacent states where there is a similar sequence of rock types, of geologic structures, and a common geologic history. Each such area in its entirety is known as a physiographic province.

In northern Sussex and Warren counties, folded and faulted limestones, shales, and sandstones of early and middle Paleozoic age belong to the Ridge and Valley Physiographic Province.

The Highlands of southern Warren and Sussex counties and northwestern Passaic, Morris, and Hunterdon counties are chiefly metamorphic rocks of Precambrian age with deep valleys of tightly infolded and infaulted Paleozoic rocks which belong to the New England Physiographic Province.

About two-thirds of New Jersey's citizens live in the one-fifth of the area of the state underlain by Triassic rocks. This Triassic lowland is part of the Piedmont Physiographic Province. It is found west of the Hudson in southern New York state and extends into New Jersey, north of a line from New Brunswick to Trenton and south of the Highlands. The Province extends south and west through Pennsylvania into Virginia.

The remaining three-fifths of New Jersey, south of the line from New Brunswick to Trenton and south or southeast of the Delaware River between Trenton and Wilmington, is known as the Coastal Plain Physiographic Province. The emerged or land portion is the northwestern thinner edge of a wedge-shaped pile of unconsolidated sands, clays, and marls of Cretaceous and Cenozoic age which extend eastward from the New Jersey coast beneath the ocean. The submerged or continental shelf part of the Coastal Plain is covered by ocean water to a maximum depth of about 600 feet. The terrain

is extremely flat and the sedimentary formations are only slightly tilted toward the southeast.

Although each of these four physiographic provinces has a distinctive geological setting and topography, it should be remembered that today's New Jersey landscape has developed as a result of erosion which began geologically only a short time ago in the Eocene epoch of the Tertiary period of the Cenozoic.

The relatively recent geologic events which by erosion etched New Jersey's valleys, hills, mountains, and plateaus out of a nearly flat featureless plain were greatly influenced by the geology of the four physiographic provinces. The drainage, the character of the soil, and minor topographic features in the northern quarter of the state were further modified by the continental glaciers of the Pleistocene. The Ice Ages also produced important but less obvious changes in the rest of New Jersey because of drastic changes in sea level. The topography thus reflects the differences in the geologic history of the four physiographic provinces. In turn, the geography and development of the several areas of the state reflect the differences in the physical environment resulting from the geologic history.

Few areas in the world can equal New Jersey in the complexity and variety of its geology. Because of this geologic variation, few areas present such marked contrasts in geography. Where else in the world is an area known as the Garden State also noted for its Pine Barrens? The per acre value of New Jersey agricultural products is the highest in the nation. At the same time more than half the state is forested and one-quarter of its area is in pine barrens which are sparsely settled, unfarmed, and covered with poor quality timber. Where else but in New Jersey, the state of contrasts, can one find a swamp where muskrat are trapped only five miles from the world's most intensely developed square mile?

II

THE HIGHLANDS

(600 million years ago)

THE OLDEST ROCKS in New Jersey are found in the area called "The Highlands." They extend in a northeast-southwest direction across northwestern Passaic, Morris and Hunterdon, and southeastern Sussex and Warren counties. Some eleven miles wide, where cut through by the Hudson River, and known as the Highlands of the Hudson, the ridges of Precambrian metamorphic rocks are about twenty-three miles wide along the New York–New Jersey line and narrow to about eight miles where cut through by the Delaware River in the vicinity of Phillipsburg. These ridges are a southward continuation of the Green or Taconic Mountains of Vermont and Massachusetts, the New England Upland of Connecticut, and the Hudson Highlands of New York. The ridges continue through Pennsylvania to the vicinity of Reading. This Reading prong of the New England Physiographic Province plunges beneath the surface of younger rocks for a distance of about fifty miles southwest of Reading and reappears where the northern end of the Blue Ridge Mountains begins to rise above the surrounding country. The Blue Ridge of the Virginia Appalachians, the mountains of New England, and the Highlands of New Jersey and New York all have a similar geologic history and character.

The metamorphism of Precambrian rocks was accomplished primarily in Precambrian time as indicated by

age determinations and by the relatively unmetamorphosed condition of the most recently emplaced Precambrian intrusive, the Mount Eve granite, which is essentially unmetamorphosed and unfolded. The folding and faulting of the Precambrian rocks during Paleozoic times is difficult to see because the rocks were already intensely deformed. At least one locality shows an intensification of folding in Paleozoic times. The overlying Hardyston quartzites indicates by its present attitude that a large Precambrian syncline west of Franklin was overturned along its east limb by the additional Paleozoic folding. Valleys have been cut in the softer shale and limestone areas of the younger Paleozoic sediments which were folded into these roots of ancient mountains. This mixture of Precambrian and Paleozoic rocks deeply buried during late Paleozoic and early Mesozoic times was again exposed at the surface in Cenozoic times.

Since the beginning of our nation "The Highlands" have had a greater effect upon the development of the colonies, and New Jersey in particular, than most of us realize. This barrier to movement to the west or northwest extends about one hundred and fifty miles from the New England hills east of the Hudson to the shores of the Schuylkill northwest of Philadelphia. The plan of the British to divide the colonies by controlling the line of the Hudson has been told to nearly every schoolchild. Most of us know how this plan was frustrated by the American Army's ability to hold West Point and to defeat Burgoyne at Saratoga. Most of us also know how the Hudson, which is tidal to Albany, was used by the Dutch to give access to the fertile limestone and shale valleys north of the Highlands. What most of us (and this includes today's citizens of New Jersey) do not appreciate is the significance of the long, low, narrow valleys which make the Highlands a series of almost parallel ridges. Nor do we realize how very few passes are provided by nature across this barrier to westward movement. The long valleys parallel to the ridges provided convenient routes of communication between New Eng-

land and the southern colonies which were protected from British attacks by the mountains to the east. With the exception of the cross-cutting valleys, such as those of the Hudson and the Delaware, the valleys of the Reading Prong are controlled by geologic structures.

A rugged wooded mass of Precambrian rocks forms the main bulk of the Ramapo and Passaic mountains with crest heights in excess of 1200 feet at the Hudson River and 800 to 1000 feet west of Bernardsville and High Bridge. The width of this part of the physiographic province ranges, from the above noted approximately eleven miles at the Hudson River to a little more than five miles at Bernardsville and High Bridge. The portion north and east of the Wanaque Valley is known as the Ramapo Mountains. The Ramapos are bisected by the Ramapo River just north of the New Jersey–New York line. The famous Ringwood and Sterling iron mines are found just to the west of this gap in the Ramapo Mountain mass.

The isolated communities of the Jackson Whites (descendants of British deserters, escaped slaves, and Indians) and the estates of millionaires around Tuxedo Park are located a few miles west of the New York Thruway and the Erie Railroad which cross the Highlands by following the low level passage of the Ramapo River.

South of the Wanaque the Precambrian mass is cut by the valley of the Pequannock and the Rockaway rivers and contains many iron mines in the Dover area along the Rockaway. Less rugged and somewhat more accessible, this section sometimes called the Passaic Mountains has numerous resort communities, summer camps, reservoirs, and watersheds serving the cities of northern New Jersey.

Northwest of the Ramapo and Passaic mountains is the narrow, deeply incised, and continuous Longwood–German Valley formed in and by a great infolded mass of Paleozoic sediments. This valley beginning in the limestone lowlands of the Hudson Valley near Monroe, New York crosses the New Jersey line at Greenwood

Lake. Traveling southwestward down this valley one would rarely reach an elevation in excess of 800 feet. At Califon, elevation 470, the valley ends as the South Branch of the Raritan River plunges into the Ken Lockwood gorge and leaves the Highlands at elevation 230 near High Bridge. The valley throughout its entire length is from 400 to 500 feet below the crest of the ridges on either side. It should be noted that some of the ridges forming the northwest border of this valley are Paleozoic sandstones and conglomerates.

The second ridge of the Highlands is notable because it is continuous from Belleville Mountain, whose bulk rises above the Hudson Valley about five miles north of the New Jersey line, to the Delaware River. No river provides a gap through this narrow two-to-five-mile-wide range. This ridge is 1500 feet high at its northern end and 800 feet high where the Delaware River cuts through at an elevation of only 125 feet above sea level. In its entire length there are only four convenient crossing places; Stockholm (1030 elevation), south of Lake Hopatcong (926 elevation), north of Schooleys Mountain (945 elevation), and via a low saddle northwest of Spruce Run (950 elevation).

The Musconetcong River west of Schooleys Mountain, which drains to the Delaware and the Wallkill west of Stockholm, which drains to the Hudson, forms a less distinct and continuous valley than the Longwood–German Valley. This second inter-Highland valley separates the Belleville-Wawayanda-Schooleys Mountain Ridge from a number of shorter and occasionally isolated ridges which bring the northwestern border of the New England Province against the Paleozoic limestones and shales of the Ridge and Valley Province.

The Precambrian rocks of northern New Jersey, like most of the Precambrian rock elsewhere in the world, are metamorphic rocks, without fossils, and contain far more metallic mineral deposits than the younger rocks. An attempt to decipher the history of Precambrian geologic events may be likened to attempting to deter-

mine the plot of a book which has been kicked around in the garage for a number of years. The order of chapters cannot be determined because the binding is broken; some pages and some sections are missing; and at key points, while much can be read, dirt conceals vital passages or the printing is obscured by deterioration of the paper. So it is with the stratigraphy and historical geology of the Precambrian. The groups of rocks may tell quite a story, but some types found in other sequences may be missing and it is difficult or impossible to be certain of their order. Within the general area of occurrence, younger formations may conceal the vital relationships. Faults, folding, and metamorphism interrupt, obscure, or obliterate fossils, detailed structures, and original mineral relationships that might provide the desired information.

In the earliest geologic reports on New Jersey the rocks of the New Jersey Highlands are called Primary and the gneissic banding was thought to be a form of stratification. The Primary designation indicated that there were no fossils. Later reports reflect increasing understanding and the changing nature of the geologic time-scale by referring to these rocks as Azoic, Archaean, or Proterozoic, and pushing the time of origin back further from the present until now the Precambrian rocks of the New Jersey Highlands are, because of the high degree of their metamorphism, considered to be early Precambrian in age.

In *Bulletin #50** and on the latest (1950) revision of the Geologic Map of New Jersey, the Precambrian rocks of the Highlands are divided into four formations; a light-colored granitoid Losee gneiss; a brown to brownish-yellow rock containing orthoclase feldspar called the Byram gneiss; a dark-colored hornblende, pyroxene, or biotite rock, the Pochuck gneiss; and the Franklin formation which is usually a marble but does include other kinds of metamorphosed sediments. Also included in the

* New Jersey Geological Survey, Bulletin 50. *The Geology of New Jersey.*

map areas of Precambrian rocks are granites, some schists in the Bayonne and Hoboken area, and gneisses and schists in the Trenton area. There are some doubts as to the age and correlation of these rocks and of the gabbro and the so-called Wissahickon mica gneiss in the vicinity of Trenton. Of these formations the Pochuck gneiss in part, the Wissahickon mica gneiss, and the Franklin formation were considered to be metamorphosed sediments while the other rock types were thought to be metamorphosed igneous rocks.

In the last twenty to thirty years there have been significant advances in the study of metamorphism in general, and the Precambrian rocks of New Jersey in particular, which have made the above-mentioned formation names obsolete and which have greatly increased our knowledge of the origin and development of the rocks in the Highlands.

The development of techniques for dating rock by measuring the products formed by the breaking down of radioactive minerals has made it possible to determine more accurately the age of igneous and metamorphic rocks. It therefore becomes possible to compare, with some certainty, sequences of Precambrian rocks in various parts of the world knowing that they are equivalent in age.

A more intensive study of the minerals, particularly the minor mineral constituents, in metamorphic rocks has developed many criteria which would indicate the degree of metamorphism which a rock has undergone as well as the nature of the original rock. These studies have proved that the Losee gneiss as originally mapped could and did include rocks which were originally sediments and others which were of igneous origin.

Careful mapping of the metamorphic changes which develop in the Paleozoic rocks of eastern New York as one moves toward New York City have shown that the marbles and schists of Manhattan Island were highly metamorphosed Paleozoic sediments. The small area of New Jersey underlain by the Manhattan schists, found in

wells and borings along the New Jersey side of the Hudson in Hoboken and Jersey City, would thus seem to be an area of Paleozoic rocks.

Similar work in the Philadelphia area indicated that the Wissahickon schist and some rocks found in the Trenton area may also be of Paleozoic age. Pegmatites and gabbro found in the Trenton area, however, can be either Precambrian or Paleozoic in age since they are found in both divisions of geologic time in the Philadelphia area. The scarcity of exposures in New Jersey will make this problem difficult, if not impossible, to solve.

For a time there was a distinct possibility that some of the less intensely metamorphosed rocks of the Highlands might be Paleozoic rather than Precambrian in age. Sufficient work has been done to indicate this is not the case in the New Jersey Highlands since the intensely metamorphosed Paleozoic rocks in the latitudes of the Highlands are all east of the Hudson along the Connecticut–New York state line.

The realization in the late 1930's that the zinc mines at Franklin would shortly be exhausted and the increased demand for iron ore during World War II occasioned several intensive and very detailed mapping and petrologic studies in the northern part of the Highlands around Franklin, Edison, Ringwood, and Dover. This work is continuing and much of the Highlands northeast of High Bridge has been remapped (1962). Although this work is far from completed, it has indicated that the terms "Bryam," "Losee," and "Pochuck" are wastebasket terms which include rock types with very diverse origins. The terms should, therefore, be abandoned for the more specific unit names based on mineral content. In the more recent work around Franklin the terms "Byram" and "Losee" have been retained, but with a very restricted application to limited rock types and map area. Pochuck has been restricted by different writers to a gneiss of igneous origin and also to another gneiss of sedimentary origin. Since the gneisses cannot be distinguished in the field, the name is useless.

In spite of the geologists' increased knowledge of metamorphic rocks and the new techniques which enable them to determine the age of rocks, there is still a great deal that is not, and cannot, be known about the Precambrian. In New Jersey the early workers recognized that some of the Precambrian rocks were much more intensely folded and metamorphosed than others, and that the Franklin marble was neither the oldest nor the youngest of the Precambrian rocks.

There are two groups of Precambrian rocks in the Highlands. The first is a series of sediments (shales, sandstones, limy sands, and perhaps some volcanics) which were intruded by granites, granodiorites, and perhaps gabbroic rocks which were all folded, faulted, and altered long before the Paleozoic began. A second quite similar series including the Franklin marble is somewhat less metamorphosed and represents a younger series of Precambrian rocks. This group, however, by the beginning of Paleozoic time was considerably metamorphosed and probably had been deeply buried by great thicknesses of sediments which themselves had been eroded by the beginning of Paleozoic time. All of these rocks were, of course, folded, faulted, and altered yet again by the deep burial and orogenic movements in Paleozoic and later times.

The Cambrian (Hardyston formation) and in other places (west side of Bearfort Mountain west of Greenwood Lake) Silurian-Devonian rocks have been deposited on folded, faulted, and metamorphosed Precambrian rocks which had been eroded to a surface of relatively low relief. The relationships at this latter location are a good example of the type of "detective work" a geologist may be required to do. In the late 1950's there was some interest in occurrences of uranium in this area. The potential ore was found both in the Devonian rocks and in the adjacent Precambrian. Some assumed that the uranium-bearing solutions were therefore Devonian in age. However, in the Devonian rocks there were boulders of uranium-bearing gneiss from the underlying Precambrian. The fact that the Devonian rested uncon-

formably on the gneiss was indicated by the fragments of the older rock in the lowest beds of the Devonian series. The absence of lower Paleozoic rocks indicates that there had been long continued erosion, possibly since Precambrian times. In any event the period of erosion had been long enough to have removed any early Paleozoic and unmetamorphosed Precambrian which might have been deposited between early or older Precambrian times and the Devonian, a time interval of well over 300 million years.

The fact that the boulders in the Devonian which had come from the Precambrian were metamorphosed and that fragments of minerals in the Devonian rocks were the minerals resulting from metamorphic changes indicated that the Precambrian had been metamorphosed before the above-mentioned long period of erosion had started. The uranium mineralization could have occurred after the Devonian except that concentrations of uranium were found to be restricted to the boulders of the metamorphosed Precambrian—a situation which could not have occurred unless the boulders had been weathered out of the Precambrian rock and become part of the Devonian sediments after the uranium mineralization had occurred.

Within the masses of Precambrian there are some unmetamorphosed quartz diorites and basaltic intrusions and a few masses of granite so slightly altered that any or all of these intrusive rocks may be Paleozoic, or in the case of the basalt, even Triassic in age. On the other hand granite or quartz diorite are so stable, or should we say require such great pressures and high temperatures before metamorphic changes occur, that they may represent igneous intrusions into the gneisses of the Highlands late in the Precambrian. The Mt. Eve granite has been dated as forming 840 million years ago. In contrast to the durable rock types, such as granite or sandstone, the minerals of basalts or of shales are much more easily altered and the presence of unmetamorphosed basaltic dikes, which are similar to those found

in the Triassic, intruding the Precambrian gneiss would suggest that these rocks are probably much younger than the Precambrian and are probably Triassic.

From the types of rocks, from the minerals that have developed, from the little bit of structure that is still preserved, from the general relationships of rocks in the area and the degree of metamorphism that has taken place, we can conclude the following about the formations and events of the Precambrian of New Jersey. All of the major formations are extremely old Precambrian. The formations must be mapped on the basis of their mineral constituents. Nearly all the rock units have been metamorphosed. As first formed, some were sediments, some were lava flows or volcanic rocks, some were intrusive igneous rocks, some (amphibolites and pyroxene-bearing amphibolites) may originally have been volcanic rocks or intrusive rocks or sedimentary rocks and others are so metamorphosed that their original character cannot be determined. The Losee gneiss at the type locality, Losee Pond (now Lake Girard), falls in this last group.

Among these Precambrian formations there are at least 24 mapable rock units; marble, quartzite, skarn, pegmatites, quartz diorite, four kinds of granite, and 15 kinds of gneisses including several granite gneisses. Perhaps the most interesting of the Precambrian formations in a number of ways and for a number of reasons is the Franklin limestone or marble or formation. What it is called depends on which report you are reading.

The Franklin formation is found at a number of places in the northwestern part of the Highlands, but by far the largest area of occurrence is in the vicinity of Franklin and Sparta. The formation is most often a coarsely crystalline white marble. In a few places the formation may be a fine grained gray dolomite, have sandy quartzite beds, or even become a slate. Within the white limestone marble phase there are dark siliceous inclusions or "black rock." These probably represent a once-continuous sandstone bed, which under the stresses and strains of folding and metamorphism has

become pulled apart like so much taffy until now the original bed is a series of discontinuous pods.

The Franklin formation grades upward and downward into gneisses which were once sedimentary rocks such as limy shales and sandy limestones. Within a sequence of metamorphic rocks which probably represent over six thousand feet of sediments, the Franklin formation is found near the center or lower middle part of the stratigraphic succession. This would suggest that in early Precambrian times an ancient sea with sandy muds on its bottom became clear, shallow, and warm enough to allow organisms or chemical action to precipitate lime ooze which later became the limestone from which the coarsely crystalline marble was eventually formed. In some places and at some times during the formation of the lime ooze, conditions of deposition changed slightly to form the "black rock" and the other siliceous phases of the formation. The dolomitic marble may have been formed during the original time of deposition, or it may have been formed later during lithification or metamorphism. At a later time, conditions again changed in this Precambrian sea and siliceous muds, rather than lime ooze, were again deposited on the ocean bottom.

Near Franklin the Franklin formation is cut by an igneous pegmatite dike. Before the dike was emplaced, the formation had been folded and metamorphosed, perhaps not so much as it is today, but to a considerable degree. The intrusion of the dike added to the total metamorphic effects which the limestone had undergone in its immediate area, but the lack of alteration in the dike itself suggests that the Franklin formation by the time the dike was intruded was much as it is now. An age determination made on minerals from this pegmatite dike indicates that it was emplaced 1160 million years ago. The Franklin formation, therefore, is much older since it was deposited, lithified, folded, and metamorphosed before the minerals in the dike crystallized from the molten rock.

Quite aside from its age, thickness, and relationship to the other metamorphic rocks of the Precambrian, the Franklin formation is of interest because of the clues it may provide as to the beginning of life. Much of the formation is limestone. Most of the Paleozoic and younger limestones were formed as a result of organic activity. The Franklin formation also contains a great deal of graphite as small specks, as large flakes, even as concentrations in pods and bands within the limestone. In Paleozoic and younger rocks most carbon is derived from organic materials. We cannot say, however, that the limestone and graphite in the Franklin formation are of organic origin. What, then, aside from the predominance of post-Paleozoic limestones and carbon compounds having an organic origin, would suggest that there was life at the time the Franklin formation was deposited?

There are several other lines of reasoning which would suggest that life existed in Franklin formation times. In Precambrian rocks elsewhere in the world, there is evidence that lime-secreting algae and primtive seaweeds were fairly common. From Paleozoic times onward there are abundant fossils of many kinds of animals, most of which have hard parts such as shells or skeletal elements which, compared to the jellyfish, slug, or worm, are easily preserved. Even today we have living forms which are soft-bodied and hardly ever preserved as fossils and algae or other primitive forms of life which precipitate calcium carbonate.

One of the world's most remarkable fossil localities is found in the Cambrian Burgess shales of British Columbia. Here the fossils are almost unique in the perfection of their preservation. There are a wide variety of forms. Not only are the soft parts of the trilobite, brachiopods, and other common fossils preserved, but there are also a large number of well preserved soft-bodied types such as jellyfish, sponges, and worms which are very rarely found as fossils.

All of the above would, then, suggest, since soft-bodied

life forms are not usually preserved as fossils, and since suddenly in Paleozoic times there are a wide variety of rather highly developed life forms with hard shells or skeletal elements, and since limestone and carbonaceous sediments are most commonly the end result of some forms of organic activity, that the Precambrian was an era in which many complex soft-bodied life forms developed from primtive lime-secreting algae, bacteria, and worms which were not likely to be preserved as fossils. Such a conclusion is consistent with a concept of orderly evolution of life forms and the concept that geologic processes in effect today are essentially the same as those in effect in the past.

To consider the Franklin formation and its contained graphite to be of inorganic origin would require geologic conditions in the distant past to have been very different from conditions today. The concept would require the evolution of life forms to have been explosive in the late Precambrian or very earliest Paleozoic. Unfortunately there are no fossils or direct evidence of organic life in the Franklin formation, thus there can be no firm conclusion as to whether or not the graphite was the result of organic activity. Nor can there be any conclusion as to whether there was any life in Precambrian times. Unproved as it is in New Jersey, it would seem reasonable to assume from evidence elsewhere in the world that the graphite in the Franklin formation is all that is left of very ancient Precambrian marine life which once existed in New Jersey.

Graphite is also found in some gneisses, and it will be interesting to see, as our knowledge and mapping of the Highlands improves, whether or not some of these graphite-bearing gneisses will in the end turn out to be more intensely metamorphosed equivalents of the Franklin formation. At one time in the Precambrian the Franklin formation probably was spread over much of northern New Jersey, just as the Paleozoic limestone covered nearly all of New Jersey at a later time. However, the normal difficulties imposed by faulting, folding,

and erosion on deciphering the record are in the Precambrian terrain complicated by metamorphism which may have actually reconstituted the whole rock.

No discussion of the geology of the Highlands is complete without mention of the mineral resources. It is in this area that geology has, aside from topography, one of its more obvious effects upon geography. It is almost axiomatic that among the first to explore any part of the world were those seeking mineral resources. After discovery, the development of the mineral commodities will depend more on whether or not there is access or a "trade route" to the mineral deposits than on any other single factor. This relationship is rather like the old question, "Which came first, the chicken or the egg?" For the mineral deposit is worthless if it cannot be reached, and a road is not usually built in a mountainous area unless there is a mineral resource that requires transportation routes capable of carrying "tonnage" for both bringing in mining equipment and taking out the ore. This is as true for the roads, canals, and railroads of New Jersey as it is for the Union Pacific (California gold) or the Santa Fe (Colorado coal and later Arizona copper).

It was mentioned earlier that the Highlands had a profound effect upon the early history of our country. Quite aside from the Durham boats which carried Washington across the Delaware (which would not have been available at all if there had been no iron ore or iron products to carry to and from Durham Furnace), the Highlands provided Washington with a perfect set of natural defensive positions from which to harass the British through much of the Revolution. The previously mentioned valleys paralleling the ridges provided the protected supply lines necessary to sustain the Army whether encamped at Valley Forge, Morristown, New Windsor, or along the Delaware in Pennsylvania. Within the valleys also were the iron ore, limestone, and water power necessary for the production of the sinews of war.

It is interesting to note that Lieutenant Bernard

Ratzer, topographer for General William Howe in 1776, included some of the roads across and through the Highlands at that time; but, although he named iron forges along Longwood Valley he did not indicate that they were connected by a road. The Highlands, however, in 1776, were inaccessible to the British topographer.

Iron forges, and therefore mining and roads in the Highlands, started as early as 1710 at Whippany. Many small operations along the fringes of the Highlands, back from the Delaware, and in from the gaps at Clinton, Morristown, and Butler which went into operation in the 1730's utilized limonite ore bodies. The 1740's (Ringwood, Oxford, and Union) and 1750's (Sterling, Ogden, Edison, and Andover) saw the beginning of operations using the larger magnetite ore bodies well within the area of the Highlands. Some twenty localities are shown on the Ratzer Map of 1776. Charlottensburg may have been burned by Tory raiders, but Ringwood, Oxford, Andover, Sterling, and Hibernia were all iron-mining operations which were busy supplying the Continental Army.

Each of these forges or furnaces was so located that the five essentials: ore, flux, fuel, power, and access to markets were easily available. Most of us fail to realize that mineral occurrence is in itself one of the least important factors in mining—once its presence in adequate quantity has been proved. The condition of iron mining in Colonial times provides an excellent example of this relationship. Each forge or furnace was near a source of iron ore, but each property also had to include large tracts of woodland for the production of charcoal, had to be underlain by or close to a source of limestone, and had to be topographically situated to permit construction of a water wheel to drive bellows and hammers. Ore concentrates could be brought in by pack mule, the limestone could be hauled short distances by cart or wagon; but to prepare the finished product a power supply for the forge and bellows was required. Delivery of the product required a road or river for transport to

A SECTION OF THE RATZER MAP OF NEW JERSEY, 1776
An early example of a map providing strategic intelligence. Prepared by Lt. Bernard Ratzer, topographer for General Howe, compiled from all available sources it shows all iron mines, forges and furnaces and the road network in an area never accessible to the British forces during the American Revolution.

Courtesy J. Warren Arnold, West Cape May, New Jersey

market. The Colonial forges in the Highlands were, with one or two exceptions, all located either in or very close to the limestone valleys of the Ridge and Valley Province on the northwest side of the Highlands, the elongate valleys of infolded Paleozoic rocks (Musconetcong, Wallkill, Longwood-German) or adjacent to the limestone exposures near Clinton at the edge of the Highlands in the Piedmont Province (Union Forge near what is now High Bridge).

Most of us tend to think of New Jersey iron ore as being the "bog iron" of the Coastal Plain or the magnetite or "mountain ore" of the Highlands. This is an oversimplification of a complex situation from the point of view of history rather than of geology or even geography. It is quite true that the earliest colonial forges and furnaces worked the limonitic or "bog iron ores" of the New Jersey Coastal Plain. It is also true that some of the earliest forges in the Highlands, even near Dover, the oldest and perhaps most important magnetite mining district in the state, were started by using local limonite "bog iron" deposits. It is true that the magnetite or mountain ores are the most important iron ores of the New Jersey Highlands. It is also true that thousands of tons of limonite and hematite ores have been extracted in the Highlands since mining began about 1710.

By 1790 all of the iron mines and pits of New Jersey were producing about ten thousand tons of iron ore per year, a major portion of which was magnetite from the Highlands. By 1830, twenty thousand tons of ore were mined. There were two serious problems—products could not be economically moved to potential markets, and the supply of wood for charcoal was fast being exhausted. The Morris Canal and Banking Company was organized in 1824 to correct both of these conditions for the magnetite mine and iron industry in the Washington, Waterloo, Netcong, Stanhope, Dover, and Boonton area. The canal, an engineering marvel of the time, with its locks and inclined planes, was completed in 1831 and could bring anthracite coal, a fuel far superior to charcoal,

close to New Jersey's largest forges and furnaces and could carry the many iron products to New York and Philadelphia markets. The Morris and Essex Railroad, completed from Newark to Dover in 1848, furnished a second, year-round, and more efficient means of getting the iron products out of the New Jersey hills. When the railroad was completed to Phillipsburg on the Delaware River in 1865, iron mining, by now chiefly magnetite, had grown to over two hundred and twenty-six thousand tons per year, an eleven-fold expansion in fifteen years, not because of a change in the ore body or even newer discoveries, but because of better fuel, better technology, and cheaper transporation to market.

Iron mining continued to grow until 1880 when there were 136, working mines and the longest list (350) of mines and prospects ever compiled. In 1880, 99 magnetite mines produced 727,790 tons of ore and 11 limonite pits produced 16,003 tons, or about 2 per cent of the total tonnage. Limonite was never again to be so important as it was in 1880 when a special effort was made to work two of the larger limonite mines in the Highlands. The tonnage climbed to 932,762 tons in 1882, a quantity not to be approached by New Jersey iron-mining operations until 1956 when the only operating mines, Mount Hope, Richards, Scrub Oaks, and Washington (Oxford) produced 912,000 long tons. In the one hundred years since 1864, the first year when over two hundred thousand tons of ore were mined, New Jersey iron mines have produced less than two hundred thousand tons during five years. For eleven years (five since 1958) the tonnage figures are not disclosed, which means that less than four mines were working. Over half a million tons of ore were mined in 26 different years. The opening of the Lake Superior ore bodies about 1880, the several economic depressions, and the development of foreign ore supplies have all had an adverse effect upon New Jersey iron ore production.

Four types of iron ore deposits have been worked in the Highlands. The very earliest workings were "bog

iron" limonite deposits similar to those in the Coastal Plain, except that the bogs were the result of the Pleistocene glaciation of the northern part of the Highlands. The working of the "bog iron" deposits soon led to the discovery of limonite ore bodies in the limestones adjacent to the gneiss ridges and to the primary magnetite ore bodies in the gneiss. Several prospecting operations, and two mines from which tonnage was extracted (Andover and Marble Hill), produced several thousand tons of hard blue or specular hematite. Of these four types of ore bodies "bog iron," limonite, magnetite, and hematite, only the magnetite deposits have been worked consistently over the years. Several of the magnetite deposits contain appreciable quantities of sulfide minerals; and a a few are rather high in titanium, an undesirable constituent, due to the presence of ilmenite. Work in the late 1950's suggests that several magnetite deposits are associated with rare earth minerals and it, of course, should be recalled that the earliest workers of the Franklin zinc ores were seeking iron. When the iron always seemed to disappear up the flue as white smoke, they recognized the fact that it was a zinc mineral rather than magnetite that they were working.

The limonite ore bodies were usually found in limestones adjacent to the gneisses of the Highlands although some few were worked in other types of rock. In each instance the limonite, formed as is the case in bog irons by the precipitation of iron oxide from ground and surface waters by the removal of carbon dioxide, was precipitated along joints, fractures, and solution openings in the host rock. In limestone, since it itself is soluble, the area for the precipitation of limonite can be sizable. Many of the deposits were close to concentrations of magnetite which supplied an abundance of iron oxide to the ground water as the outcropping weathered.

The hematite ore bodies, although never important economically, are of theoretical interest. All are located very close to the top of the ridges in which they are found. Most of the occurrences seem to be in rocks which

may be standstone or shale phases of the Franklin formation. One can speculate as to whether these deposits are secondary enrichments, similar to Precambrian iron ore deposits found in the Lake Superior region, resulting from deep weathering in Precambrian times in New Jersey. These secondary enrichments, on the other hand, may be remnants of a deep weathering in early Tertiary times when the surface of New Jersey was at, or close to, the level indicated by today's flat-topped ridges.

The magnetite deposits have been studied since the earliest days of geology. As has been previously indicated, the gneissic banding in the rocks of the Highlands was at first believed to indicate sedimentary structures. Since the occurrence of most magnetite concentrations is parallel to and closely controlled by the metamorphic structures or foliation in the rock and since most, if not all, of the gneisses in which the magnetite is found were once sediments, the conclusion of early workers that the magnetite was originally concentrated in, and was part of, the sediments from which the gneisses were derived is not unreasonable. By about 1910 enough studies of the magnetite ore bodies had been made and enough learned about the characteristics of metamorphic rocks to indicate that the magnetite had been introduced into the host rocks by hot aqueous solutions from deep-seated igneous activity so that W. S. Bayley concluded, "They may be called, in short, igneous veins."

Bayley's work, *Iron Mines and Mining in New Jersey*, published in 1910, was completed soon enough after the peak years of iron-mining operation so that it is a definitive study. It also benefited from the inclusion of much information from magnetite surveys of the Highlands completed for Thomas A. Edison. This remarkable man not only conducted a magnetic survey of the Highlands to find natural concentrations of magnetite but also developed magnetic concentrators, endless belt conveyors, and briquetting machines during the 1890's in an effort to develop a method for the large-scale working of low-grade magnetite occurrences. About ten thousand tons

of high-grade magnetite concentrate briquettes were shipped from the Edison Mine near Ogdensburg in 1899, but the whole operation was some thirty years ahead of its time. Magnetic concentrators or separators are now used extensively in magnetite ore processing. Conveyor belts are used for a wide variety of mineral and other transporting operations. Briquetting of low-grade Lake Superior ores is now being attempted. Patriotic Jerseymen might call this a fitting fate for the iron ore deposits which so effectively reduced iron mining in New Jersey.

After the publication of Bayley's work, very little was written about New Jersey magnetite deposits until the previously mentioned investigations during World War II were completed. In the intervening decades a great deal had been learned about metamorphic rocks and igneous intrusions. The physical chemistry involved in both metamorphism and igneous activity was not understood until recently. Ore deposits such as these, where the ore mineral replacement of other minerals is obviously related to igneous activity, were impossible to explain on the basis of hydrothermal solutions because the rocks themselves were impermeable. It is now recognized that during the intrusion of granitic bodies considerable volumes of material may move in a gaseous state through the space lattices or molecules of the rock-forming minerals and be precipitated as replacement minerals hundreds and perhaps even thousands of feet from the intrusion. There may also be simultaneous deposition of minerals from hydrothermal solutions—Bayley's "igneous veins." This increased knowledge of metamorphism and the mechanisms of igneous intrusion has solved many of the problems of mineral relationships and the origin of the more complex magnetite and sulphide mineral deposits which could not be adequately explained by geologists and mineralogists at the beginning of the century. As our knowledge increases, further studies of some of the New Jersey ore bodies will be in order and it is conceivable that some new ore bodies

will be worked and old ore bodies reopened as our mineral economy changes.

In minor details there are many variations in the magnetite ore bodies. The larger, workable ore bodies are all tabular, lens-shaped, high-grade concentrations of magnetite which closely parallel the gneissic banding of the country rock and follow the plunging elongation of mineral orientation (lineation). If you can imagine two or more lens-shaped planks being slightly canted and plunged diagonally into the ground, you can gain a fair concept of the relation of the ore bodies to the containing rock. Some mines have one or two closely parallel concentrations of nearly solid magnetite rock separated by gneisses of the wall or country rock almost devoid of magnetite. Along the plunge or inclination of the ore bodies or ore shoots, they may pinch and swell like so many beans on a string. Walls or the edge of the magnetite concentration may be abrupt or there may be narrow parallel bands of ore separated by wider and wider bands of gneiss without ore.

To be minable, there must be enough ore mineral (in this case, magnetite) in the total volume of rock that must be removed so that the resulting concentrate will pay all the costs of mining, milling (crushing), and concentrating (separation). Often some minor mineral element or some product resulting from the concentration of the ore mineral may actually make the profit in the operation. In at least one New Jersey operation, sand resulting from the crushing of the ore, to permit the magnetite to be removed by the magnetic separators, has made a substantial contribution to the operating revenue because it could be sold for highway construction. In another case in a different part of the concentrating operation, zircon, with a high per ton value, can be recovered at almost no cost. Changes in mining methods may also cause subsantial changes in cost and, overnight, may make gangue or waste rock into ore. In one New Jersey mine, the difference between profit and loss was de-

termined by placing the primary or first crusher two thousand feet below the surface. This, in effect, nearly doubled the efficiency of the skips or buckets which brought the ore to the surface without investment in new hoisting facilities.

The dimensions of the magnetite concentrations, of course, change from mine to mine and ore body to ore body. The ore bodies average from 5 to 20 feet in width with the largest reaching 75 feet. Vertically the ore bodies are about 200 feet high with some reaching 450 feet. Ore bodies have been worked as much as 11,000 feet along the direction of inclination. The deepest New Jersey mine is a little over 2000 feet deep.

No discussion of the Highlands is complete without a word about the zinc deposits of Franklin and Sterling Hill in Sussex County. As early as 1730, the area was known as the "copper tract" apparently because the red zincite (as yet unidentified) was thought to be cuprite. An unsuccessful attempt was made in 1770 to work the black franklinite, also unidentified and thought to be magnetite, for its iron content. The true nature of the ore body was recognized in 1810 when Dr. Archibald Bruce of New York City identified zincite. The other ore minerals, franklinite and willemite, were identified in 1819 and 1824. In all, between 1810 and 1953, 33 minerals or mineral varieties were first found at Franklin or Sterling Hill.

The most complete work on Franklin is Palache's United States Geological Survey Professional Paper, No. 180, published in 1937. Palache's concepts as to the origin and the mineral zones in the deposit have been challenged but the reference is still eagerly sought. In response to the demand of mineral collectors, the long out-of-print paper was reprinted by the United States Geological Survey in 1960. In 1956, a geologic map compiled by geologists of the New Jersey Zinc Company, J. M. Hague, J. L. Baum, L. A. Herrmann, and R. J. Pickering, was published in Volume LXVII of the *Bulletin* of the Geological Society of America.

The ore, about 40 per cent black franklinite, 23 per cent green or red brown willemite, and 1 per cent red zincite, is unique in that the franklinite and zincite are unknown elsewhere. The gangue minerals are carbonates (25 per cent) and silicates (11 per cent). The complexity of the deposit is world famous; only the famous mines at Langban, Sweden, equal the Franklin area zinc deposits in the number of minerals, over two hundred, which have been found in one place. The Franklin ores are also unusual in their high (10 per cent) content of manganese whose atoms substitute for zinc or iron in the molecules of franklinite, willemite, and zincite.

Both ore bodies are in the Franklin limestone. At Franklin, which was worked out and abandoned in 1954 after over one hundred years of operation by the New Jersey Zinc Company, the boundaries between the ore and the limestone are sharp. The ore body in plan view and in northwest-southeast vertical section resembles a fish hook with the long sides on the northwest and the loop of the hook to the southwest in plan and slanted downward toward the southeast in section. The Sterling Hill ore body is elliptical, almost amoeboid in shape with irregular banding, discontinuous masses of ore, and irregular boundaries. The Sterling Hill ore body has been worked sporadically since 1870. It will probably continue in production for many years.

The origin of these complex ore bodies is, and probably will remain, one of the great unsolved geologic mysteries. The Franklin ore body contained many more minerals, and more of the unusual minerals, than the Sterling Hill mass because it was found in association with pegmatite dikes. There is no agreement that the ore body was metamorphosed along with the Franklin formation. There would also seem to be no agreement that the iron and zinc minerals, like the magnetite of the iron mines, were introduced into the limestone by pneumatolytic (hot gases) and/or hydrothermal (hot water) action resulting from nearby igneous intrusions. The greatest disagreement comes in the interpretation

of the significance of mineral relationships where the ore body and the pegmatites intersect. There is good evidence that the pegmatite came after the ore and some say even better evidence that the pegmatite intruded the limestone before the ore was formed. The ore is a gneiss and we can only speculate as to what the ore minerals once were.

The Franklin mine was worked out in 1954, and thus ended an era of new mineral discoveries. However, new minerals will probably continue to be discovered as old Franklin and new Sterling Hill specimens are studied.

In 1955, "doverite," a yttrium-bearing rare earth mineral, which had long been erroneously identified as hematite iron staining on the iron ore was found in the Scrub Oaks mine in the Dover district. Various uranium minerals and occurrences and some monazite (thorium mineralization) have been found in the Highlands since 1955. At the Bemco uranium rare earth prospect near Cranberry Lake, the rare earth mineral "spencite" was found and described. The discovery of the mineral in Canada and publication of its description a few weeks ahead of a paper on the New Jersey find prevented the mineral from being named "bemcoite."

The Highlands, as a geologic unit, like New Jersey, are an area of contrasts. Perhaps the least known and least understood of the geologic regions, one part of it (Franklin) is world famous and perhaps better known in some circles than all the rest of the state. A barrier to transportation and growth, the Highlands contain mineral resources which have forced the development of roads, canals, and railroads through its passes and valleys. Extremely isolated from the world in some areas, it is swarming with summer visitors in others. The oldest geology in the state is still the newest in the study and discovery of minerals and information about the geologic processes by which they are formed.

III

THE NORTHERN VALLEYS
(600 to 350 million years ago)

MANY GEOLOGISTS feel that the Paleozoic Era is the most interesting in geologic history because of its fossils, the variation in the geologic formations, and the events of more than 300 million years which can be deciphered from the sediments deposited so long ago. In New Jersey the challenge to geologists is greater than in most other places in eastern North America because the area is smaller, the formations thinner, and perhaps more has happened, leaving less of a record to tell the tale. New Jersey is the transition zone between the different geologic history of the northern Appalachians found in New York State and New England and the southern Appalachians of Pennsylvania and southward.

Most of the Paleozoic rocks found in New Jersey are in the Ridge and Valley Physiographic Province north of the Highlands in northern Sussex and Warren counties. The Ridge and Valley Province extends from the St. Lawrence lowland through Lake Champlain and the Valley of the Hudson, southwestward through New Jersey and Pennsylvania, and on for a total length of 1200 miles to Tennessee and northern Alabama. In New Jersey the whole province has only three main parts: (1) Kittatinny Valley, part of the Great Valley; (2) a ridge, Kittatinny Mountain; and (3) the Minisink Valley occupied by the Delaware River. The Ridge and Valley

Province has a total width of 14 miles on the New York–New Jersey line. Westward in Pennsylvania the province assumes its more characteristic form, a series of valley floors separated by flat-topped ridges, and reaches its greatest width of 80 miles. The ridges and valleys have been formed by differential erosion. The upturned edges of the folded limestone and shales have been more quickly eroded than sandstone and conglomerate. The valleys are, therefore, underlain by limestone and shale while the sandstones preserve the ridges.

In the New Jersey section of the Ridge and Valley Province all of the formations have a general northwesterly tilt so that the formations are progressively younger the farther you go from the southeastern border where the Cambrian rocks lie upon the much older Precambrian. In Pennsylvania and to the south there has been more intense folding and the formations are repeated in the succession of ridges and valleys. In New Jersey almost all of the province was covered by the Pleistocene glaciers. The terrain is often concealed by glacial deposits such as sand and gravel terraces, or the clays of Great Meadows, the bottom deposits of an Ice Age lake. Glacial materials have blocked older drainage channels leaving Culvers Lake, Lake Owassa, Swartswood Lake, and others. On Kittatinny Mountain the ice sheets have scoured out the rock basin lakes such as Sunfish Pond, Lake Marcia, and Lakes Mohonk and Minnewaska in New York State. Only the small section of limestone valley east of the Delaware River downstream from and south of Belvidere is unglaciated.

Like the Great Valley of which it is a part, the Kittatinny Valley has two levels. The areas underlain by shale are some 200 to 400 feet higher than the adjacent parts of the valley underlain by limestone. Unlike the Great Valley elsewhere the southeastern border of the Ridge and Valley Province in New Jersey is complicated by mountain remnants (Scott, Jenny Jump, and Pochuck Mountains) which are outliers of the main mass of the Highlands to the southeast.

Limestone and shale valleys such as those around Vernon on the New York State line or in the valley of the Musconetcong or around Phillipsburg while geologically part of the Ridge and Valley Province are generally considered as part of the Highlands Province.

Kittatinny Mountain, which is called Shawangunk Mountain in New York State and Blue Mountain in Pennsylvania, starts about 10 miles southwest of the Hudson River near Kingston, New York. It rises abruptly as an almost unbroken escarpment of the Silurian Shawangunk conglomerate with the mountain crest 450 to 650 feet above and only 200 to 400 yards west of the shale hills at the foot of the slope at the northwest edge of the Kittatinny Valley. The mountain, 1803 feet high at High Point, has a remarkably level top. The top of the mountain is at times a double-crested ridge, at other times a plateau nearly four miles wide, or as it nears the Delaware Water Gap, a single narrow ridge. The wall of Kittatinny Mountain is broken in New Jersey at Culvers Gap, more than 400 feet below the crest, which was traversed by the early Minisink Indian trails to the sea, and colonial roads from New York to Pennsylvania. A saddle near Catfish Pond about 100 feet below the summit is the only break in the rampart between Culvers Gap and the famous and spectacular Delaware Water Gap. The Delaware River has cut through Kittatinny Mountain at an elevation now only 283 feet above sea level. On either side the ridge has an elevation of 1400 feet. The Gap is 300 yards wide at river level and 1500 yards wide at the crest. The base of the mountain through which the Delaware cut its gorge is a trifle over two miles through. The river also cuts through the shale foothills in a continuation of the gorge about 300 feet deep for another mile and a half. The fame of this scenic feature probably rests equally on the size of the cut in solid rock and the fact that it is visible as a giant cleft in the flat-topped horizon from every hilltop in the Kittatinny Valley open to the north within twenty miles or more of the Gap.

DELAWARE WATER GAP

The line shows the large fold in the Shawangunk strata which form the cliffs on the New Jersey side of the river.

New Jersey Department Conservation and Economic Development

North of the Kittatinny Mountain ridge the Delaware flows through the Minisink Valley. The northwest side of this valley is formed by sandstone and shales. These form the scarp of the Pocono Plateau whose crest is some 600 feet above the river. The Delaware follows a trough, cut nearly 100 feet deep in the upturned edge of Devonian shale, filled with Pleistocene gravels from Port Jervis, where it comes out of the Pocono Plateau, to Wallpack Bend. At Wallpack Bend the Delaware reverses its course twice within one and one-half miles to cross Wallpack Ridge, a minor ridge in the Minisink Valley, formed by the Devonian Oriskany sandstone and Esopus grit (caudi-galli grit of the early reports, a rather indistinct marking on the bedding planes of the sandstone, believed to be a fossil seaweed). South of Wallpack Bend and on to Delaware Water Gap, the Delaware again follows a drift-filled valley cut in soft strata immediately above or in the upper part of the Silurian High Falls sandstone. In New Jersey east of Wallpack Bend this buried drift-filled valley is followed by the Flat Brook. The Minisink Valley itself extends from just west of Kingston on the Hudson through the area occupied by the Delaware River and on into Pennsylvania to and beyond the Lehigh River. This was an important trade route in Indian and Colonial times and was followed by the Dutch when they built the Old Mine Road to Pahaquarry.

The Paleozoic, as indicated in the first chapter, is the "dawn of life." In its rocks, in contrast to the Precambrian, fossils are abundant. The life forms are preserved as fossils not only because they had hard shells and later skeletons, but also because there were many more types and varieties of life. The names of the geologic periods in the Paleozoic have already been used to some extent in this chapter. It might be useful and help fix their position in the time scale to review briefly the order and origin of the period names. The periods or divisions of the Paleozoic era are: Cambrian, Ordovician, Silurian, Devonian, Mississippian, Pennsylvanian, and Permian (to

THE NEW JERSEY SIDE OF THE DELAWARE WATER GAP

Note the folding of the Shawangunk beds at the left. The low ground to the right is typical of the Martinsburg Terrain.

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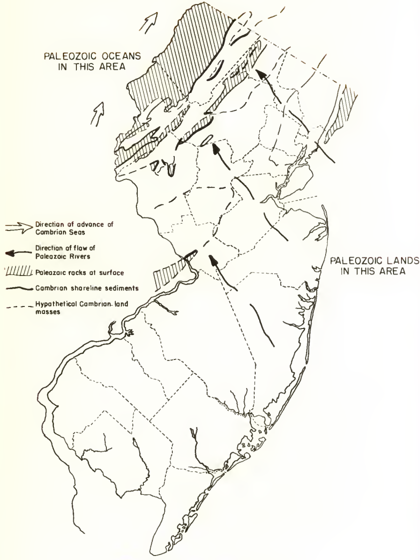
remember them think of: *Come, Over, Some, Day, Maybe, Play, Poker*)—they vary in duration from 100 million to as little as 40 million years. Each period is named, except the Ordovician, which should be New Yorkian, for an area of the world where the fossil forms identifying rocks of that period are found in abundance and where the stratigraphic sequence was first studied. Cambria is the ancient name of Wales. The Silures were the tribe that first lived in northern Wales. Devonian stands for Devonshire and the other periods stand for the Mississippi Valley, the Pennsylvania coal fields, and the province of Perm on the western flank of the Russian Ural Mountains. The Ordovician is named for an ancient tribe of central Wales, the Ordovices, because the first Ordovician fossils were described from central Wales. The best and most fossiliferous Ordovician section, however, is found in New York State. Rocks from the Cambrian through the Devonian periods are found in New Jersey. The younger Paleozoic rocks occur north and west of New Jersey beyond the Delaware River in the Pocono Mountains of Pennsylvania and the Catskill Mountains of New York.

As indicated above, most of the Paleozoic rocks in New Jersey are found as successively younger beds when moving in a northwesterly direction. The oldest Paleozoic rocks occur along the southeastern border of the Ridge and Valley Physiographic Province at the many places where the Cambrian Hardyston formation lies unconformably on the Precambrian Highlands. However, Paleozoic rocks are also found south of the Precambrian Highlands as at Trenton where the Cambrian Hardyston quartzite is found folded and faulted in the tongue of Precambrian rocks exposed between the Triassic rocks on the north and the Coastal Plain sediments on the south.

Small areas of lower Paleozoic rocks are also exposed, because of the removal of the overlying Triassic sediments, at Clinton and Peapack, among other places, along the Highland border. Within the Highlands middle



PALEOZOIC NEW JERSEY

Paleozoic (Silurian and Devonian) rocks form the ridges of Green Pond and Bearfort Mountains and underlie the northern part of the Longwood–German Valley. Lower Paleozoic limestones and shales underlie the southern part of this valley, the areas around Vernon and Sparta and the Musconetcong Valley southwest from Hackettstown. Highly metamorphosed rocks beneath the waterfront of Hoboken and Jersey City, as indicated in the chapter on Precambrian rocks, are now thought to be of Paleozoic age. So, while we are apt to think of northern Sussex and Warren counties for Paleozoic rocks found in New Jersey, we should always remember that small exposures found in other parts of the state indicate the wide expanse of the Paleozoic seas which once covered New Jersey.

Before discussing the events of Paleozoic times, the significance of two geologic terms "unconformity" and "revolution or disturbance" should be made clear. "Unconformity" is applied to the contact of one formation with another when it indicates that erosion has taken place and part of the geologic record is missing. Various names are used by geologists when talking to other geologists in order to save descriptive statements. The general concept, however, is most important to a proper understanding of historical geology and the detective work geologists must often do to learn of the conditions which existed in ancient times.

The Hardyston quartzite has been deposited on Precambrian rocks at a number of places in New Jersey. The unconformity may be old soil or a weathered zone marked by a few inches of highly micaceous material (pinite) or the encroaching sea may have washed the rock bare before the first sands and gravels were deposited. In any event, the Precambrian rocks have very obviously been folded, metamorphosed, and truncated by erosion before the Cambrian sediments were deposited upon them.

In the Green Pond area at some places Silurian rocks are found resting on the Precambrian, yet at other places

nearby Devonian rocks rest on the Precambrian. In the Green Pond area, therefore, there are from 200 to 250 million more years of missing record than in the areas where Hardyston lies unconformably on the Precambrian. What is not clear in the Green Pond area is whether the Hardyston and the younger limestones were deposited and then later removed by erosion or whether there had been only erosion during all of early Paleozoic time. Not all unconformities represent such long periods of erosion. More commonly, minor unconformities are found between geologic formations belonging to the same geologic period. Thus, an unconformity may represent an erosion interval of only a few millions of years or of many, many millions of years.

Unconformities which indicate erosion and loss of the geologic record also indicate crustal movements. In many of the texts on historical geology these periods of crustal movement, called "disturbances," are placed at the ends of geologic periods, and those at the end of the geologic era are called "revolutions." The episodes of mountain making in effect are used to punctuate the geologic time scale. Instead of having folding, faulting, uplift, or sinking of the crust occurring as compact episodes at the end of each period and as a revolution at the end of the Paleozoic era, the more modern concept envisions the Appalachian Revolution, which so altered all of eastern North America, as a series of local episodes or disturbances now here and now there, extending progressively further southward from Newfoundland to Alabama and occurring in time from the Cambrian through the Permian and perhaps into the Triassic.

In New Jersey and adjacent areas the unconformities, the relative degree of folding and faulting, and the missing sedimentary deposits would suggest that major crustal movements took place at least in the late Ordovician or early Silurian, during the Devonian, and during the Permian and early Triassic.

Recent studies of the Appalachian deformation (the why of ridges, valleys, folds, and faults) suggest that

great subcrustal movements may have occurred across southern New Jersey, roughly on a line from Lakehurst through Mount Holly. A push from the southeast in the area of the New Jersey coast deformed the Precambrian rocks of the Highlands and pushed parts of them (the above-mentioned isolated masses of Scotts Mountain, etc.) onto the younger sediments which had been laid down in early Paleozoic times. The Paleozoic sediments themselves were folded, eroded, buried, and folded yet again as the crust was shortened and the land rose from beneath the sea or was submerged as each mountain-making movement occurred and died away. New Jersey, more than her neighboring states, has had the record of this changing continental margin in Paleozoic times preserved in the folding and faulting of some of the Paleozoic rocks into areas, such as the Longwood–German Valley, between the very hard erosion-resistant Precambrian rocks of the Highlands.

Within the above-described framework of space and time for the Ridge and Valley Physiographic Province in New Jersey, let us examine the most important Paleozoic formations and the clues they provide as to the conditions which existed so long ago. The crust of the earth under New Jersey will seem at times to have been extremely mobile so that we can imagine that earthquakes were a daily occurrence. However, we should always remember that the story of approximately one-tenth of the land area of New Jersey with Paleozoic rocks at the surface is the story of over half of all geologic time since the beginning of the Paleozoic. The later chapters will cover sediments and rocks deposited in the ensuing 180 milion years, a time interval about as long as that needed to deposit the sediments which now form the Kittatinny Valley.

The oldest of the Paleozoic formations in New Jersey is the lower Cambrian Hardyston quartzite. Ranging from a few feet to as much as 200 feet in thickness, the formation is usually a sandstone or a conglomerate with fragments from the underlying Precambrian rocks. In

its upper part it becomes shaly or limey and it grades into the the overlying limestone formation without a distinct boundary.

The Hardyston formation is found as a narrow band along the southeastern border of Kittatinny Valley, in some parts of the inter-Highland Valleys, and south of the Highlands at Clinton. Found also at Trenton, its eastern Pennslyvania (Philadelphia area) equivalent (Chickies) and its Dutchess County New York equivalent (Poughquag) indicate that the Cambrian seas were extremely widespread. As previously mentioned, in some locations a thin layer of pinite suggests deposition of the first stratum on an old soil. At other places the encroaching seas apparently washed the rocks clean before depositing the beach sand. In a very few places several fossil worm borings *(scolithus)* have been found. The finding of the lower Cambrian trilobite, *Olenellus,* is reported. The quartzite has been used as a building stone, but it has a tendency to weather gray or brown which is now considered an objectionable characteristic for bulding stone.

As the seas invaded New Jersey from the southwest and the beaches developed farther and farther to the north and east on the land referred to as Appalachia, the shallow offshore banks began to develop calcareous ooze much as it is being developed today in the Bahamas. The accumulation of the lime kept pace with the rising sea, or sinking ocean bottom, for today we have at least 2300 feet of Cambrian dolomites and limestones. Beds with oölites (a beach feature), reefs (bioherms) of lime-secreting algae, ripple marks, and crossbedding all indicate continuous deposition in shallow water. The limestone also indicates that Appalachia was a low-lying land drained by rivers without much mud or silt, since this would kill the lime-secreting algae and appear in the sedimentary record as thick shales.

The New Jersey geologic map shows the name and symbol for Kittatinny limestone for all of the Cambrian and Ordovician limestones above the Hardyston. The

limestones are so similar that the formations can be divided only after the geologist has become familiar with minor changes in sedimentary character. The presence of oölites, of shaly layers, characteristic occurrences of chert, changes in color, and changes in thickness of beds must be used to distinguish formations. Fossils are neither common nor diagnostic. The Kittatinny limestone is now divided into the Leithsville, the Limeport, and the Allentown formations of Cambrian age and the Ordovician Beekmantown.

In the northern part of the Appalachians there were crustal movements as early as middle Cambrian and major movements and vulcanism in the Ordovician and Silurian. In the New Jersey area these are indicated by slight and local periods of non-deposition without folding (disconformities) and the presence of some thin layers of bentonite or volcanic ash. The unconformity between the Cambrian and Ordovician limestones is not always present, indicating that in some areas of New Jersey there was continued deposition of lime ooze.

Like the Hardyston, the limestone probably covered all of what is now northern and central New Jersey. The limestone is found to the south of the Highlands where the Triassic has been removed by erosion. The metamorphic equivalents of some of these formations may appear on Manhattan Island and north of Philadelphia.

Fossils other than the lime-secreting algae are rare, but the abundance of fossils in exposures of Cambrian and Ordovician rocks in other areas indicate that the New Jersey seas of this period had unfavorable conditions for the survival or preservation of many marine forms. The upper limestones (Ordovician Beekmantown) is characterized by an abundance of chert and the presence of thin layers of siliceous silt. The chert suggests an abundance of sponges whose skeletons consist of silica rods and hooks. The silt layers are perhaps the foreshadows of coming events.

Evidence in the Musconetcong Valley as compared to evidence from limestone exposed in northern Sussex

County suggests that about 300 feet of the uppermost Beekmantown was removed in the Musconetcong Valley before the deposition of the Jacksonburg formation.

The Jacksonburg resembles the Hardyston in that it is another thin but significant formation. This highly fossiliferous, dark-blue to black, high-calcium limestone may have a maximum thickness in excess of 200 feet. It rests unconformably on the earlier Ordovician Beekmantown. Sometimes the Jacksonburg has Beekmantown boulders in its lowest beds. Within the formation there is a disconformity and an abrupt change in fossil content. The upper beds have a great deal of interbedded shale and were once thought to grade into the overlying Martinsburg formation. Faulting seems to be fairly common along the formation's upper surface. In some areas the entire formation may have been faulted out for a distance of several miles.

The Jacksonburg, because of the high-calcium lower beds and the high-alumina upper shales and limestone, is a natural cement rock which is worked extensively in the Lehigh Valley for some forty miles westward from Martins Creek, which is on the west bank of the Delaware River north of Easton. New Jersey's two cement operations have been out of business for more than thirty years and this emphasizes again that an ore is only an ore when there is a profit to be made in extracting the rock or mineral.

The higher levels of the Kittatinny Valley are underlain by the Martinsburg formation which may lie unconformably upon the Jacksonburg, or where the Jacksonburg has been removed by faulting, on the Beekmantown. The true nature of the change from Jacksonburg to Martinsburg has not yet been determined. In some papers on stratigraphy the change from Jacksonburg to Martinsburg is said to be gradational; in others it is called an unconformity. Whatever the condition, earlier light-colored limestone pebbles in the basal Jacksonburg and a conglomerate layer of its own fragments between the purer limestone of the lower Jacksonburg

and the shaly limestone of the upper Jacksonburg indicate crustal movements in middle Ordovician times.

The Martinsburg shale, or as some authorities now call it the Martinsburg group, consists of 3500 feet of the lower black shales or slates, the Dauphin formation of upper or late Ordovician age of eastern Pennsylvania, and about 500 feet of standstone which is even younger than the shale. In the older geologic reports of New Jersey and New York these are called the Hudson River shales from their equivalent beds in the Hudson River Valley. The black shales of the upper part of the Martinsburg continue north in the Hudson Valley and are also found in the Mohawk Valley west of Albany. In New York State, in addition to being able to subdivide the black shales, the strata equivalent to the lower part of the Martinsburg of New Jersey are limestones of the Trenton group (named after Trenton Falls, New York—not Trenton, New Jersey). Westward in Pennsylvania there are several equivalents of the Martinsburg shale and also a thick sandstone, the Juniata, which is conformable above the highest Martinsburg but is not found in New Jersey.

All of the Martinsburg shales in New Jersey have well-developed cleavage and in some areas are actually slates. The bulk of the slate, however, is west of the Delaware River near Bangor and Pen Argyl. Slate was worked for a short time in New Jersey near Columbus on the Delaware. The development of a slaty cleavage usually destroys fossils. In the Martinsburg fossils are rare, but enough have been found in and close to New Jersey so that the lower and upper parts of the Martinsburg can be rather precisely located in the geologic time scale. For those who would like this precision, the Martinsburg shale was deposited from Trenton times (upper Middle Ordovician) through Pulaski times (middle Upper Ordovician).

South of the Highlands in the vicinity of Clinton shales which have been classified as equivalent to the Martinsburg are found at the surface stratigraphically

above the Kittatinny limestone. The Jacksonburg is shown on the geologic map as would be expected between the two formations. Recent work suggests that the Jacksonburg may have been faulted out.

After the deposition of the Martinsburg shale, along with its upper sandy beds, and probably a good bit more of the sequence which does not show at the present surface, folding with uplift and erosion took place. Upon the upturned edges of the Martinsburg was deposited Silurian Shawangunk conglomerate which forms the crest of Kittatinny ridge. Before considering the Silurian and Devonian rocks, it would seem advisable to attempt to reconstruct the sequence of events during Cambrian and Ordovician times as revealed by the nature of the sediments and the presence or absence of unconformities.

In New Jersey the late Precambrian rocks are missing and the Hardyston quartzite indicates that seas from the southwest flooded the ancient land mass except for the general area of today's northern Highlands. This land mass, which lay to the east of New Jersey, may have been a series of large islands like Japan or the Philippines or perhaps a subcontinent. It was a low-lying land mass during all of Cambrian and early Ordovician times. Streams did not carry sediments, or there were no streams so that, once the shallow seas had deepened a little beyond the breaker zone, lime ooze developed on the ocean bottom. Oölites, ripple marks, and other sedimentary features indicate formation of several thousand feet of limestone in clear, warm shallow waters. From time to time local areas were raised close to or above the surface as indicated by mud-cracks and intraformational conglomerates. Perhaps some of these areas were eroded for a short time (a million years or so), before deposition of lime again occurred. The absence of fossils, except for the lime-secreting algae and later possibly sponges seems to indicate that the area was a submarine desert with respect to the life known to be thriving in the seas elsewhere.

The occasional uplifting and erosion of the sea bottom

was a reflection of the much more extensive and deep-seated crustal movements in Newfoundland, Canada, and New England during the Cambrian and Ordovician times.

Fairly early in Ordovician times after the deposition of only a thousand or so feet of limestone, crustal movements in and near New Jersey uplifted and eroded some of the sea bottom. At the same time the eastern land mass of Appalachia was also raised so that mud was carried by streams into the bordering sea. With the mixture of mud and lime ooze came a flood of marine life so that the Jacksonburg, as compared to the older limestones, is rich in fossils.

The uplifting of Appalachia, as shown by the shale beds of the Beekmantown limestone and the shaly lime of the Jacksonburg, quickened. The mud and sand from the bordering streams filled the marginal seas as Appalachia rose and the great thickness of the Martinsburg shales with its standstone beds was deposited. To the east in New York State the land had not yet risen, as the earlier equivalents of the Martinsburg shale is the Trenton limestone. To the west the uplift may have continued longer and would seem to have been higher. Instead of shale, the thin sandstone beds of the Juniata formation were deposited. Toward the end of the Ordovician the crustal movements to the north had become more severe, and in New Jersey the Cambrian and lower Ordovician limestones and upper Ordovician shales were folded and eroded throughout the area which is now New Jersey.

Very interesting recent work based on analogies found in the Alps suggest that the Martinsburg was folded and cleavage developed while it was still a relatively unlithified mud containing a great deal of water. It also suggests that some blocks of the Precambrian crystallines which formed Appalachia were lifted high enough to slide downhill northwestward across and upon the water-bearing, lightly consolidated Paleozoic muds; this process gave us the locally more intense folding of some

rocks and the outlying thrust block of Jenny Jump Mountain, which is separated from the main mass of the Highlands to the southeast. This thrust movement has heretofore been thought to have occurred during the crustal movements in the latter part of the Paleozoic.

In any event, folding, uplift, and erosion of the Cambrian and Ordovician rocks took place during the Taconic disturbance—the name for a rather widespread crustal movement in the northern Appalachians at the end of the Ordovician—so that the early Silurian Shawangunk conglomerate was deposited over much of northern New Jersey, southern New York, and eastern Pennsylvania. The Shawangunk formation of New York and New Jersey, the Tuscarora quartzite of Pennsylvania, or the Oneida conglomerate of early geologic reports are composed of small white quartz pebbles in a siliceous matrix which may be blue-gray, greenish-yellow, or even red. The formation ranges in thickness from 1500 feet at Delaware Water Gap to 650 feet at the New York state line. Southwest of Kingston, New York, on the Hudson River the conglomerate disappears entirely from the stratigraphic sequence. Slate pebbles and occasionally beds of black shale a few inches thick are found in the formation. At Delaware Water Gap and near Otisville primitive fish—eurypterid—fossils have been found in the black shales.

The Shawangunk conglomerate is characterized by crossbedding and the previously mentioned rounded white quartz pebbles. The rounded pebbles indicate that the material has been transported a long distance; the crossbedding, that it was deposited by streams in a delta or in an alluvial fan. Alluvial fans would be formed on land. The eurypterids would then have lived in the rivers which crossed the plain. Another fossil, *Arthrophycus alleghaniense,* is similar to some modern worms found on sand beaches, thus suggesting delta deposits in a marine environment.

The Green Pond conglomerate found on Green Pond and adjacent mountains on both sides of Green Pond

in Morris County is considered the equivalent of the Shawangunk. However, the Silurian conglomerate rests directly upon the Precambrian which raises the interesting question as to whether the Cambrian and Ordovician sandstones, limestones, and shales found in the extension of the valley to the southwest were ever present in the northern part of the Highlands. In any event, the Silurian deltaic or alluvial fan deposits covered all of northwestern New Jersey and a considerable area of the Highlands as well.

The Shawangunk conglomerate grades upward into some 2000 feet of alternating reddish and greenish shales of the High Falls formation of New Jersey and New York or the Bloomsburg formation of Pennsylvania. In the upper part of the formation soft red shales predominate and the topmost 700 to 800 feet of beds are now concealed by thick glacial deposits which have filled the pre-Pleistocene valley. This weak layer flooring a deep valley now filled with glacial deposits is followed southwestward by the Flat Brook until it joins the Delaware at Wallpack Bend. From here the Delaware follows the strike of the upper part of the High Falls formation to Delaware Water Gap.

The absence of fossils in the High Falls formation makes correlation difficult both to the northeast in New York and to the southwest in Pennsylvania. This monotonous series of sandstones without fossils or identifiable unconformities thickens outside New Jersey into various identifiably different and separable sandstones ranging over a considerable segment of Silurian time.

The equivalent of the High Falls formation in the Longwood Valley area of the northern Highlands is about 200 feet of Longwood red shale. These shales which most nearly resemble the red shales at the top of the High Falls formation, as seen on the Pennsylvania side of the Delaware River near Delaware Water Gap, raise again the question of non-deposition or the equivalence of different types of unfossiliferous sediments.

The often rapid changes in the type of sediments deposited from one area to another during the same period of geologic time, and the abundance of the common sedimentary rocks in each and every geologic period force geologists to correlate sedimentary formations by the use of fossils. In the case at hand, the absence of fossils makes precise dating of the various parts of the High Falls, and its Longwood shale equivalent, impossible. If an index fossil or a number of different kinds of fossils were present, the problem of determining the age of the various parts of the formation would cease to exist.

Before discussing the several thin, highly fossiliferous, and easily identified formations which follow the great thicknesses of almost unfossiliferous sandstones of the High Falls and the limestones and shales of the earlier Paleozoic formations, it might be well to digress for a moment and explain the use of fossils and index fossils.

Some fossils such as trilobites, dinosaurs, or mammals are limited almost completely to a geologic era such as the Paleozoic, Mesozoic, or Cenozoic. Others such as the brachiopod are found all the way from the Cambrian on or with the algae, jellyfish, and some worms from the Precambrian. Still others such as fish, land plants, corals, and reptiles have definite starting points in the time scale such as the Silurian or Devonian. Finally, within many animal and plant groups there are varieties or genera or species which are distinctive, have migrated over large areas, have been preserved as fossils, and yet have lived only for an instant of geologic time. Fossils of this last kind are known as index fossils. If, in the upper part of the High Falls, corals were to be found, they would indicate a Devonian age; the presence of a few primitive fish suggests a Silurian age, but does not rule out an early Devonian age. If, however, the worm tubes of *Arthrophycus alleghaniense* of the underlying Shawangunk were found in the lower part of the High Falls or in the Longwood shales, then an early Silurian age could be assigned with certainty. In some formations fossils

are abundant and change so rapidly that it is possible to correlate the age of the formation almost bed by bed. On the other hand, a thick formation may be so devoid of signficant fossils that it can only be dated as having been deposited within a geologic period.

West of Wallpack Bend the High Falls is found on the Pennsylvania side of the Delaware River. To the east of the Bend on the west side of the Flat Brook Valley are five Silurian formations from 12 to 50 feet thick with a total thickness of 150 to 200 feet. Forming the slope above are another 300 feet of strata consisting of five Devonian formations. The crest of the Wallpack ridge is some 500 feet of Devonian Oriskany sandstone and Esopus grit. The west slope down to the Delaware River is underlain by the Devonian Onondaga shale and along the river by traces of the Devonian Marcellus shale.

In the Green Pond Mountain area, as was also the case in Silurian times, shales, sandstones, and conglomerates of considerable thickness (3500 to 4000 feet in four formations) were deposited during Devonian times. In contrast to the Silurian formations, which were similar lithologically in the Green Pond area and along the Delaware, the Devonian sediments represent near-shore or terrestrial detrital deposits in the Green Pond area and rapidly changing offshore marine deposits in the area of the Delaware River Valley. Two of the latest Silurian and five of the early Devonian formations of the Delaware Valley are missing from the Green Pond–Longwood Valley area. The formations, however, are found a short distance to the northeast in New York State.

The story of the ebb and flow of the late Silurian and early Devonian seas, of the rapid change from erosion to deposition and back to erosion, is too complex to give here. In New Jersey three or ten or thirty feet of fossiliferous limestone can be correlated with hundreds of feet of sediments in New York or Pennsylvania.

Fossils, while abundant in some places, are extremely

difficult to get out of the rocks in New Jersey. Fossil collecting is more successful in our neighboring states where the beds are thicker, fossil reefs more common, and the formations less inclined to dolomites or cherts which can be beaten to a powder without giving up their fossils.

The shales of the middle Devonian Hamilton group form the west side of the valley of the upper Delaware. These are capped by the shales, flagstones, and sandstones of the continental formations of the great Catskill delta whose red and green sandstones form the Pocono Plateau and the Catskill Mountains northwest and northeast of New Jersey beyond the Delaware River.

In Europe the Mississippian and Pennsylvanian periods are called the Carboniferous. These rocks and the Permian are found in central and western Pennsylvania and complete the Paleozoic stratigraphy for the eastern United States. In New Jersey there are no rocks representing any of geologic time between the late Devonian and the early Triassic.

IV

THE MID-STATE AREA

(200 million years ago)

MOST VISITORS, and many of our citizens, think New Jersey consists of the red shale lowland between Trenton and Newark, the Palisades of the Hudson, and the seashore on the east side of the Pine Barrens. The history of the development of the Triassic rocks of the red shale lowland and the Palisades in the mid-New Jersey Piedmont is perhaps of interest to more New Jersey citizens because nearly four million of our more than six million people live in this part of the state. The awesome thoughts evoked by the words "dinosaurs" and "lava flows" have a certain popular appeal and contribute to this interest in Triassic times, as do the well reported and rare fossil finds and the "zeolite minerals" found in the Watchung lava flows.

One-fifth of New Jersey is within the Piedmont Physiographic Province which extends southwestward from the Hudson River, between the Coastal Plain and the Highlands, or further south between the Blue Ridge and the older Appalachians, into Georgia and Alabama. In New Jersey almost all of the Piedmont is within the Triassic lowland of this Province. A small wedge-shaped area at Trenton, pointing toward Princeton Junction, widens westward around Philadelphia. The Precambrian and highly metamorphosed Paleozoics of this wedge are more typical of the rocks of the rest of the Piedmont to

the southwest than are the Triassic rocks which underlie central New Jersey.

The border between the Highlands and the Piedmont is marked by a nearly straight fault-line valley extending southwestward from the Hudson at Stony Point to the vicinity of Boonton and Morristown. The Precambrian rocks form a high prominent ridge to the northwest while conglomerates, basalts, or even shale form lower hills in the Piedmont on the southeast side of the border fault valley. South of Morristown the boundary is again abrupt and marked by a fault valley extending to the vicinity of Far Hills and Bedminster. From here to the Delaware River the Piedmont border is partly an unconformity of Triassic on Precambrian, sometimes marked by faults which bring Precambrian against Triassic, and locally, as at Clinton, marked by small areas of pre-Triassic rock, exposed by the erosion of the Triassic, which are in fault contact with or rest unconformably upon the Precambrian of the Highlands. From Far Hills to Peapack-Gladstone and from Hamden to High Bridge the usual northeast-southwest trend of the Highlands-Piedmont border changes to a northwest-southeast direction because of distinct five to ten miles offsets of the Precambrian ridges.

Much of the eastern border of the Triassic and of the Piedmont is concealed. From Stony Point, New York, to Hoboken, New Jersey, it is beneath the Hudson River, from Hokoben to Jersey City beneath buildings and city streets, and thence to Bayonne and Staten Island beneath bay mud, water, and vegetation. From Staten Island to near Princeton the border is beneath the overlapping Cretaceous sediments of the Coastal Plain. At Hoboken, Jersey City, Staten Island, and from Princeton to Trenton, Precambrian and Paleozoic rocks form the eastern border of the Piedmont.

An outlier or erosional remnant of Coastal Plain sediments, crossed by U. S. Route 1 at Sand Hill, east of Princeton, lies within the Piedmont. The underlying, hard erosion-resistant diabase has protected the capping

Cretaceous or younger sands from removal by the streams which have laid bare the underlying Triassic rocks for a width of two or three miles south of this outlying remnant of the Coastal Plain. West from Princeton Junction the Coastal Plain sediments rest upon the older Precambrian and highly metamorhposed early Paleozoic rocks which form the bulk of the Piedmont Province to the south.

Triassic rocks were first studied in England where the terrestrial sediments, in many ways similar to those found in New Jersey, were called the "New Red Sandstones" to distinguish them from the Devonian "Old Red Sandstone." In Germany a marine formation, the Muschelkalk, was found between the upper and lower red sandstones. This three-fold division of red sandstone, white chalk, and red sandstone formed such a striking natural unit in so many parts of Germany that the name "Trias" became well established before a more usual locality name could be given the series.

In eastern North America only the upper Triassic is represented. First called the Newark group in 1856 by W. E. Redfield for the occurrences in the Newark area, the name was not generally accepted until the stratigraphic sequence of the New Jersey Triassic basin had been worked out in 1897 by H. B. Kummel, the third New Jersey State Geologist. The Triassic rocks in the six major elongate basins and several minor basins which are found from Nova Scotia to North Carolina typically consist of a sandstone sequence, a shale sequence, diabase or basalt intrusives, and in some of the northern basins, basalt lava flows.

The sediments were deposited on land in deeply eroded basins upon folded and faulted Paleozoic and Precambrian rocks. As is the usual case with terrestrial sediments, fossils are extremely rare. A few vertebrate fossils, however, have been found which indicate that the Newark series is upper Triassic in age. This age and the character of the series also indicates that eastern North America, during much of Triassic times, was un-

dergoing a prolonged period of erosion. Erosion and terrestrial sediments seem to be characteristic of Triassic times throughout most of North America. Marine Triassic rocks are restricted to California and the far west. The Chinle formation, a series of terrestrial sediments which contain the Painted Desert and the Petrified Forest of Arizona, two of America's more spectacular natural wonders, is equivalent in age to the lower part of the Newark series. New Jersey has some Triassic petrified wood and several colors in the Triassic sediments. Most of the Triassic sediments in New Jersey are concealed by urban development or vegetation and most outcroppings have rather drab colors so we must go west to view nature in fancy dress.

The longest, from the Hudson River to central Virginia, and widest, thirty miles adjacent to the Delaware River, Triassic basin in eastern North America has its northern end in New Jersey. The Triassic strata dips towards the northwest and the basal arkose, a red sandstone formation, an upper red shale formation, and three lava flows are matched by an equivalent sequence of Triassic rocks in Connecticut where all the formations have an easterly dip. Since the intervening area of eastern New York and western Connecticut is only slightly greater in width than the area covered by the lava flows in the basins, it has been suggested that the Triassic sediments deposited in New Jersey and Connecticut were once part of a single great valley. Evidence from fossils seems to be against such a concept. Some of the evidence as to the conditions of origin of the sediments also suggests that deposition of the Triassic sandstones was in part from this central up-arched area. Thus it seems more reasonable to assume that instead of a post-Triassic arching upward of the center of a single great valley filled with Triassic sediments which extended from New Jersey to Connecticut, deposition in Triassic times took place in two separate valleys. The presence of three series of lava flows in both valleys is coincidental rather than proof that there was once a single valley.

Whether deposition was in one large or several smaller basins the magnitude of crustal movements, the thickness of the deposited sediments, the volcanic activity, the unusual climate, and the strange forms of plant and animal life as revealed by the sedimentation, stratigraphy, and geologic structures make the Triassic times unlike anything found elsewhere in the geologic history of eastern North America.

The rift valleys of Africa are the nearst present approximation to conditions in the Triassic. High mountains border the elongate valleys in which large lakes and swamps are found; streams rushing out of the mountains deposit extensive alluvial fans in the valleys. Volcanoes are found along the borders both in the rift valleys and in the adjacent highlands. The only thing missing in today's scene is the presence of dinosaurs—but then, we now have man and perhaps he is more interesting than the ancient reptiles.

The border fault from Boonton to Stony Point truncates more than 10,000 feet of Triassic sandstones, shales, and lava flows, indicating a series of sporadic movements along the fault over several millions of years. The Triassic is 45 million years long and in New Jersey we have only the upper part—less than a third of the time is still 10 million years. Between Peapack and Lebanon conditions suggest that toward the end of Triassic times the great valley had been filled and sediments were lapping over the edge of the now much-eroded mountains that had once towered over the valley on its northwest side. West of Clinton there is an alluvial fan which extends outward some five miles. Its finer material, carried into the valley, would extend the radius of the fan as far again.

The surface upon which the Triassic sediments were deposited as exposed near Clinton has a relief of at least 200 feet. Borings for the Spruce Run Reservoir into the underlying limestone show cavities at least this deep below the old land surface. Many of the limestone sinks in the Triassic surface (probably a line of foothills) are

filled with red sand and mud and red stained fragments of the surficial limestone. Along the Delaware River the sediments are 12,000 feet or more in thickness. Near Princeton the basal sandstones received material from the southeast. At Frenchtown on the Delaware, limestone pebbles from limestone beds now eroded from the Highlands or from the Paleozoic rocks in the valleys north of the Highlands are abundant.

The three basalt sheets of the Watchung Mountains cover an area at present of over five hundred square miles and attain thicknesses of as much as eight hundred feet. The Palisades sill reaches nearly a thousand feet in its thickest cross section. The sill intrudes sediments in the basin for a length of nearly eighty miles from Haverstraw, New York, to Hopewell, New Jersey. The ring dike of Cushetunk Mountain consists of a sheet of diabase more than a hundred feet thick dipping outward at an angle of from 50° to 80° from the horizontal. It encloses and cuts across the shales under Round Valley which is about three and a half miles long by about a mile and a half wide. Basalt dikes at several places may be measured in tens of feet in width and from hundreds of feet in length to the eight miles of the Flemington–Copper Hill–Rocktown dike. Such are the dimensions and nature of some of the more important Triassic features in New Jersey.

Of all the Triassic basins, that part of the New Jersey–Virginia basin found in Hunterdon and Mercer counties in New Jersey and in Bucks and Montgomery counties in Pennsylvania contains nearly all of the distinctive Lockatong argillite lithology. It is not a time stratigraphic unit in the usual sense, but rather a rock which reveals unusual local sedimentary conditions occurring at the same time as that in which sandstone and shale were being deposited in other parts of the basin. The argillite is restricted to one part of one of the Triassic basins, just as coal is restricted to the Richmond basin and lava flows are restricted to the northern Triassic basins. Of its significance and origin, more later.

The New Jersey area underlain by Triassic rocks should be considered in two segments; that north and east of a line from New Brunswick to Somerville to Peapack-Gladstone and that found to the south and west of this line. In the former the general dip is to the northwest and the sedimentary formations are apparently unrepeated from the Hudson River on the east to the border fault on the west. This segment of the Triassic basin contains three exposures of lava flows, no argillite, and only one major intrusive, the Palisades sill. In the western segment, or main part of the basin, major faults cause a repetition of the stratigraphic sequence which here contains argillite. There are no lava flows in this section, but there are several large intrusive masses and numerous minor dikes and plugs. Stockton standstone and Brunswick shale are common throughout the basin. Fanglomerates are found along the northwest border and a basal sandstone is exposed along the southeast border.

The Stockton formation, named for its occurrence in quarries around Stockton on the Delaware, is a light-colored arkosic sandstone with interbedded red sandstone and shale. It is found along the eastern border of the Triassic basin from Trenton as far north as Nyack on the Hudson. Quite yellow near Princeton Junction, it is more commonly light pink, or brownish red but may sometimes be a dark purple-red. Commonly known as "brownstone," it is the principal building stone of many, if not most, of the major historic buildings found in central New Jersey, such as Old Queen's at Rutgers and Nassau Hall at Princeton. It is perhaps even better known for its use in the acres of apartments and tenements constructed at the turn of the century in our major eastern cities. Stockton sandstone or "brownstone" was shipped by canal boat or schooner from quarries along the Delaware, the Connecticut, the Hudson and from other areas of occurrence along the canals and rivers which crossed the Triassic basins. The Stockton formation is from 2300 to 3100 feet thick and rests unconformably on the underlying Precambrian and

metamorphosed Paleozoics from which it was derived by northwestward flowing streams of the lowlands bordering the Triassic basin to the southwest. The Stockton sandstone–Brunswick shale sequence is the usual stratigraphic succession found in all the Triassic basins of eastern North America with the Stockton normally grading upward into the red Brunswick shale. There is no evidence of an unconformity, and sandstone beds are found in the Brunswick formation and occasional shale beds are found in the Stockton.

The Brunswick formation is usually a soft red shale with the above-mentioned interbedded sandstone most common in its lower part. Named for its outcropping along the Raritan River at New Brunswick, it is the most common rock type in northeastern New Jersey. In the area north of Paterson and Newark, however, much that is mapped as shale is actually sandstone, some of which is enough like the Stockton to have been quarried. From six to eight thousand feet thick, it underlies the Hackensack Meadows, Newark, and almost all of the area between the Palisades and the Watchungs. A thickness of 600 feet is found in the valley between the First and Second Watchung ridges. Between the individual lava flows of the Watchungs there may be as much as a hundred feet of shale. Above the second Watchung flows about twelve hundred feet of shale was deposited before the outpouring of the third Watchung flows which form Long Hill, Hook Mountain, and the other trap ridges within the crescent of the First and Second Watchung Mountains. Gentle, relatively open fold structures in the upper part of the Triassic formations are shown by the curving of these traprock ridges and the change in direction of the strike of the shale wherever it may be exposed. The basalt ridge in Harding Township between New Vernon and Green Village is the edge of an anticlinal dome truncated by erosion. The basalt of this ridge is part of the same lava flow that forms Long Hill to the east. This is the only instance in New Jersey in which lava flows are exposed twice by folding

and the similarity in surface form to basalt occurrences further to the west should not be construed to indicate a similar origin for these western basalt ridges. Brunswick red shale is found above this third series of lava flows (south of the New Vèrnon ridge) but the thickness cannot be determined because so much of the shale has been removed by erosion.

Just as streams entering the Triassic Valley from the southeast because of decreased velocity dropped their load of sand to form the Stockton sandstone, so streams entering the valley from the northwest dropped their sand, gravel, and boulders to form the fanglomerates. The northwestern border must have been extremely mountainous because the streams entering the Triassic Valley had sufficient velocity to move boulders up to 18 inches in diameter, and occasionally moved even larger boulders, as is evidenced along Route 202 northeast of Pompton. Such conditions prevail in streams coming out of high mountain areas today. The southeast side of the valley, on the other hand, must have been a region of low rolling hills with a thick soil cover from which only mud and sand-size fragments could be derived and transported.

These alluvial fans or fanglomerates found along the northwest border consist almost exclusively of sandstone, quartzite, and limestone pebbles and boulders. Gneisses appear only in the fan near Montville. This suggests that the crystalline rocks now exposed in the Highlands were covered in Triassic times, except in the vicinity of Montville, by a mantle of Paleozoic sandstones and limestones. In Bergen and Passaic counties the fanglomerates are less well developed than to the south, but conglomerate and sandstone beds are frequently found well out toward the middle of the basin in the Brunswick shale (see exposures on the New York Thruway and Garden State Parkway) suggesting that the bordering mountains had a lower elevation or that the Triassic basin at its northern end was less well developed. A narrower range of particle size (gravel to mud) and a wider dis-

tribution of similar size material suggests a more uniform gradient in the streams coming out of the mountain and flowing across the basin. This can be achieved by having either lower mountains or a less deep basin so that there is not the sudden change in slope found where the large alluvial fans of coarse material are formed.

The largest of the Triassic border alluvial fans, as indicated by the extensive deposits of fanglomerates, are found west of Clinton. The most dramatic exposures anywhere in New Jersey, showing the character of the fanglomerates, are found in the cliff on the New Jersey side of the Delaware River north of Frenchtown. The cliffs about a mile away on the Pennsylvania side of the river are far enough removed from the point where the ancient Triassic gorges emptied into the basin so that almost no pebbles or boulders were carried westward into this part of the alluvial fans formed by the ancient streams. In this section of the Triassic basin the terrain must have been most striking. The great alluvial fans at their outermost (southern) edges were depositing their material in the large playa lakes of the main basin. The Triassic topography is indicated by the argillites of the Hunterdon Plateau which to the north of Pittstown interfinger with the fanglomerates of the Clinton area.

The Lockatong argillite is found between the Stockton and Brunswick formations in a massive band representing a thickness of between one thousand and nineteen hundred feet. Several thinner bands in the section add at least another thousand feet of argillite to the stratigraphic column. On the geologic map of the State the argillite is shown as a formation. The Lockatong is named after Lockatong Creek, a tributary of the Delaware which has its source in the Hunterdon Plateau north of Stockton. It has always been difficult to determine in some areas of outcroping whether the rocks are red shale or red argillite. The former weathers into a pile of fragments in a year or two while the latter is a good building stone which lasts for centuries. In some

outcroppings it is obvious which rock is present, but difficulties develop when the individual beds must be distinguished. Detailed studies of the argillite had to await modern methods and instruments. The development of the X-ray and powder method for determining the chemical composition of minerals and rocks has solved many of the problems. Many of the argillite beds are like the beds of shale except for their very high soda content, a condition which is so unusual that an authoritative work on the chemical characteristics of rocks carried for many years a chemical analysis of argillite which was in error, because the author thought the typist had transposed the values for sodium and potassium and corrected the alleged mistake in the final proof.

In the 1950's Dean B. McLaughlin did a great deal of detailed work on the argillites west of the Delaware River in Pennsylvania and proved that the several bands of distinctive lithology could be mapped, that shale and argillite did alternate in the stratigraphic column many times, and that the argillite was not a separate formation but rather a type of rock or "lithofacies" which interfingers most commonly with the lowest part of the Brunswick shale and with the Stockton sandstone. He also proved that at intervals high in the stratigraphic column in the younger Brunswick shale, argillite sequences reappeared for short intervals.

F. B. Van Houten has shown that the Lockatong represents deposits of mud and precipitates formed in a great playa lake or lakes in the Triassic Valley. For perhaps five million years in this part of the Triassic basin during the time of deposition of much of the Stockton and Brunswick formations, there were cyclic changes in the climate during which the sediments mapped as argillite and the unmapped argillite bands in the Brunswick shale were deposited.

At times the valley received enough rainfall to cause full flowing streams to drain the basin to the sea. After several hundred thousand years the climate cycle changed

to arid. During this long dry spell large salt lakes would form and even these would decrease in size and dry up as the droughts reached their peaks. The massive argillite formed in the earlier period of basin-filling probably marks the time of the most severe climate, prolonged drought, and the largest or most abundant argillite lakes. These major changes in the climatic cycles continued upward with lessening severity into the Brunswick formation, with the periods of maximum dryness marked by a group of argillite beds in the shale. Each of these major cycles took about half a million years. At their maximum the argillite lakes covered an area at least twenty-five miles wide by ninety miles long.

The minor changes and fluctuations of weather are marked by the minor variations in sedimentary conditions. The minor cycles of about twenty-two thousand years are repeated again and again throughout the stratigraphic thickness. Each cycle includes from seven to twenty-two feet of different beds. The cyclic variations may be divided into several types or units with characteristic sedimentary and mineralogical associations. Two types of cycles predominate; a detrital or wet weather cycle and a chemical precipitate or severe drought cycle. Black shales with plant remains or thin fingers of shale and conglomerate extending into the argillite begin the detrital cycles and indicate heavy rains which flooded and filled the basins in the wet part of the cycle. As rainfall decreased, the sediments indicate that the lakes become stagnant and more shallow. Calcite, dolomite, and the soda-rich mineral, analcime, were deposited in the late stages during which the lakes dried out and vast mud flats with pools of concentrated brine, similar perhaps to the mud flats of the Kalahari desert of southwest Africa today, were left to dry out, crack, and compact as the water was evaporated by the sun. The shortest of the minor climatic cycles (22,000 years) was still long enough for a considerable fauna and flora to develop during the wet years.

Most of the fossils found in the argillite are found in

the lowest black shales which mark the beginning of a wet cycle or in the carbonate-rich mudstones which initiated the chemical type cycles.

Fish skeletons found near Boonton and at Princeton, the bones of crocodile-like reptiles found near Fort Lee, and the shells of shrimplike relatives of the modern barnacle found at a number of places all raise the interesting speculation as to whether the Triassic basin in mid-New Jersey was during wet cycles connected to the sea or whether there was always an estuarian section of the basin. Several of the fish and invertebrate forms are brackish-water animals which could have lived either in playa lakes or in estuaries connected to the sea. Landlocked salmon found in today's lakes in many areas prove that normally marine animals can be trapped in and survive in lakes cut off from the sea. This would have been possible during many of the repeated climatic changes in the Triassic when drainage from the basin reached the sea. A theory of playa lakes would thus be an acceptable one to explain the life forms found as fossils.

There is also always the possibility that in the central New Jersey area, the Triassic "rift valley" is like the northwest end of the Red Sea where the Egyptians pursuing Moses were drowned, or like the delta of the Sacramento River in the Great Valley of California today. The Triassic Golden Gate long ago disappeared, like mythical Atlantis, beneath the sea which once covered the Coastal Plain. However, later erosion may have exposed a Triassic equivalent of the tidal marshes around Sacramento, the records of which have been preserved in the sediments at Princeton and Boonton. Such an interpretation of the sedimentary record would then explain the brackish water forms as living in estuaries continually connected to the Triassic sea.

Since the Lockatong contains so many beds of mud and marl, it has the best environment for the preservation of Triassic fossil remains and tracks. At a few places, however, muddy areas of what we now call the Stockton

sandstone, and the more abundant mud flats and swamps of the Brunswick shale, have also preserved the bones and tracks of the Triassic inhabitants of New Jersey. Again, however, the presence of some of the fossils and the fossil tracks raises a question. This time it is one of interpretation of the record and mapping. Fossils in the older works are reported from all three "formations," but as descriptions are rechecked and field work redone with modern methods, the question continually arises as to whether the fossil locality is not really in one of the areas of "argillite lakes" rather than in a Stockton or Brunswick swamp environment. With respect to the brackish water forms, the answer would almost always seem to be "argillite." However, the answer is less easy to apply to the detrital fragments of the cycads and conifers, which must be buried quickly in fine-grained sediments if they are to be preserved. Since they are most logically wet cycle fossils, the proper environment could also be found in the shale and sandstone.

With dinosaur tracks and flying reptiles, we have a different problem. These animals could move from one basin to another and thus a single animal could make fossil footprints in Connecticut and New Jersey. Although the tracks tell us little about the possible climate where they are found, except that the ground was muddy, the evolution of the dinosaurs and, therefore, the tracks they make provide index fossils useful for dating equivalent beds in the various parts of the Triassic basins.

Life in the Triassic swamps—there was very little or none in the extreme deserts—was somewhat like the present with cycads and conifers and some rather modern looking reptilian forms. The most common ingredients of our present flora and fauna were lacking. Flowering plants had not yet appeared and the few mammalian forms which existed were very small and primitive.

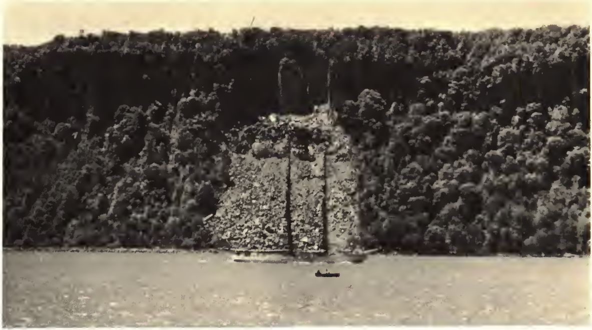
Late in the Triassic, as the great basin that was Central Jersey became filled with thousands of feet of sediments, igneous activity, called the Palisades disturbance by some, resulted in the outpouring of lava from feeder

pipes and dikes along the northwest side of the Triassic basin and intrusions of basalt or diabase elsewhere. Basaltic lavas are quite fluid and free flowing so that great areas of the basin were quickly covered by lava. As indicated earlier in this chapter, there were three volcanic episodes which formed what are now called the First, Second, and Third Watchung Mountains, and each sequence of lava flows is separated from the next by a period during which hundreds of feet of shale and sandstone were deposited. However, it should be noted that each Watchung Ridge of Mountain consists of one or more lava flows. Some lava flows followed the first outpouring before the lava top could weather. In other areas the lava flow had weathered considerably, or had even been covered by occasional thin patches of sediments, before the next batch of basalt sloshed into the area. Together the individual flows built up a thickness of several hundred feet of basalt.

Although pipes, dikes, and other intrusive bodies are now found in the Triassic sediments and intruding the bordering gneisses in adjacent parts of the highlands, there is no proof that these dikes and pipes were the sources of the several widespread outpourings of lava. It would seem probable that some may be, but no direct connections have been observed and most such intrusives are found outside the area enclosed by the First Watchung Mountain. It would seem more probable that most of the several dikes and plugs are part of the last or at least a late episode of vulcanism.

Sometime during the later part of all of the deep-seated activity which heated up the molten basalt, and on three occasions forced it to the surface, the plumbing became clogged and some of the material instead of reaching the surface was intruded between the sedimentary beds to form the Palisades sill of diabase rock.

The Palisades sill intrudes shale beds high in the section, but correlation between shales on the east and west sides of the basin is difficult so that the relationship between the intrusion of the sill and the outpourings of the



THE PALISADES

Columnar jointing of the Palisades of the Hudson north of Fort Lee. An unusually large rock fall from the collapse of several columns, as indicated by the wide area of talus behind the schooner, occurred about 1950, a short time before the picture was taken. The bottom of the diabase sill which is underlain by Stockton sandstone is at the top of the uniform talus slope level with the top of the schooner foremast.

Professor Charles Harp, Trenton State College

Watchung lavas is indeterminate. An intrusive phase younger or later than the Third Watchung phase would seem most logical, but the intrusion could have taken place earlier. For the moment the age relationships between the sill and the flows must remain an enigma. It should also be noted that the bulk of the traprock in the other Triassic basins occurs as intrusive bodies. Extrusive basalts are found only in New Jersey, Connecticut, and Nova Scotia.

Diabase is a chemical and mineralogical but more slowly cooled equivalent of basalt. Basalt poured forth on the surface cools quickly before the minerals can form large crystals. The upper part of the basalt flow or surface develops gas pockets or bubbles, called vesicles, just like the head develops on the amber brew when it leaves the confining pressure of the bottle, can, or keg. A "ropey" surface or "pahoehoe" lava forms, as the very top surface of the molten material freezes quickly forming a fine-grained basalt which, like scum on a stream, is rolled up by the moving liquid beneath. Basalt is a gray or black uniform rock with submicroscopic crystals of feldspar, pyroxene, and olivine. Diabase, dolerites, gabbro, or other intrusive equivalents of basalt on the other hand, having been forced between sediments deep below the surface of the earth, require tens, if not hundreds or thousands, of years to cool and so develop visible crystals. Where a network of small elongate or lathlike crystals of the mineral plagioclase are enclosed by larger crystals of pyroxene the rock is said to be a diabase. In other areas and in other times the basalt minerals may crystallize at a different rate and we have a different kind of rock such as a dolerite or olivine gabbro with mineral grains more equal in size and less interlocked with each other. The very crystalline character which gives diabase its name, also gives it a toughness which reduces wear by abrasion, rendering it more useful either as "rip-rap" (very large blocks) to protect the New Jersey Coast or as aggregate (crushed gravel-size stone) to be used in New Jersey highways. Because of

nature's thoughtfulness in giving us three ridges of basalt and a great sill of diabase, in the area between two of the world's larger cities, New Jersey often leads the nation in the quantity of "diabase or basalt type" traprock which is mined or quarried every year.

The Palisades differ from the Watchungs in other ways besides the speed of solidification and the size of the mineral grains. Where lavas follow the irregular surface over which they flow and have little effect upon the underlying rocks, an intrusive works between or cuts across the strata and alters the intruded rock for a considerable distance (tens to hundreds of feet) both above and below. A sill, as a form of intrusive rock, is, in general, parallel to the beds of the inruded strata. Dikes and plugs, on the other hand, cut across the strata at an acute angle. The Palisades sill, while it is generally parallel to the intruded strata, from time to time for short distances, cuts across beds or sends out single, branchlike intrusives for a considerable distance. In New York State near Nyack and in New Jersey near Princeton in the Griggstown–Rocky Hill area, the Palisades sill has an arcuate form and cuts across a great thickness of early and late Newark series rocks, thus indicating that it was intruded late in Newark times even though most of the sill is intruded between the lower beds of the series. At the end, the Palisades sill cuts across strata so steeply that it resembles a dike.

Intrusive plugs, dikes, ring dikes, and a rather odd-shaped intrusive best described as half-dike and half-sill are found beyond both ends of the Palisades sill. The longest in length, largest in size, and most abundant intrusives are found at the southwest end of the sill in Mercer and Hunterdon counties. Some geologists interpret the Sourland Mountain sill north of Hopewell as a continuation of the Palisades sill. If this is correct the sill would then extend into Pennsylvania and would originally, before faulting, have been 20 to 25 miles longer. The Sourland Mountain sill, however, intrudes a much lower part of the stratigraphic section than the

dikelike mass south of Hopewell on the other side of the fault. It would thus seem to be a different intrusive from that forming the west end of the Palisades.

Many geologic cross sections of New Jersey show the Palisades sill originating, like the Watchungs, in the area of the northwestern border fault. At first glance, this is a reasonable assumption particularly since the sill seems to parallel the low angle northwesterly dip of the sandstone in northern New Jersey. Recent geologic studies in the Hackensack Meadows, however, confirm the concepts of one of the earlier students of the Palisades sill, who was thirty years ahead of his time, that the dip of the sill steepens suddenly beneath the meadows and therefore the sill probably originates along a buried fault line at the eastern edge of the Triassic basin. Other bits of evidence make it seem more logical to think of the molten rock which formed the Palisades as having risen along these faults which, by late Triassic times, had been deeply buried by the sands of the Stockton formation and the mud of the Brunswick shale in the eastern part of the basin. The diabase magma thus found it easier to intrude and lift the great thickness of overlying sediments than to break through to the surface. On the west side of the basin, in contrast, the faults may still have been active. Because there may have been a foothill belt in the pre-Triassic, the sedimentary cover was probably thin as compared to the sediments on the east side of the basin. Thus everything was favorable on the west side of the "rift valley" for the molten rock to break forth as a series of lava flows.

When the Palisades intrusive was emplaced, heat baked and altered a few tens of feet of strata beneath the molten mass and, since heat tends to rise to the surface, several tens and sometimes even a hundred feet of the overlying sediments were baked and altered. Near Fort Lee the sandstone changes color a bit. Near Princeton the red shale became a hornfels, a gray almost vitreous and very hard rock, along both intrusive contacts. The hot gases (boron, silica, and water) also developed

small spots of tourmaline in the hornfels close to the top contact of the sill. Unlike the lava flow, the intrusive cannot quickly release its volatile and aqueous constituents, the metamorphic effects upon the adjacent rock may therefore be profound. In the case of the Palisades sill in addition to the spotted hornfels, there were areas such as those at Griggstown and Arlington where copper minerals were deposited. At other locations such as Bergen Hill, zeolite minerals accumulated in fractures, joints, and other openings.

When an intrusive body, such as sill, is thick and has been intruded at a very low angle to the horizontal, several interesting phenomena develop. The Palisades sill is thick enough to develop the columnar jointing which gives it the resemblance to a colonial stockade or palisades along the Hudson River—hence the name—and to have cooled slowly enough to permit gravitational settling of the mineral crystals formed in the early stages of solidification.

Each of the long vertical columns of diabase revealed in the cliffs along the west side of the Hudson is a hexagonal prism produced in the last stages of cooling of the molten material. As the magma cooled it contracted about the centers of solidification. The stresses set up by the contraction of a thick mass are most easily relieved by a hexagonal break pattern which produces the column perpendicular to the borders of the mass. This columnar jointing is often found in sills, not infrequently in thick dikes where the columns may be horizontal, in thick lava flows (rare but observable in New Jersey), and even in volcanic necks (Devils Tower, Wyoming).

The crystal settling, on the other hand, is restricted to thick, flat-lying intrusive bodies. In the crystallization of any igneous rocks, the minerals form in a definite order as the mass cools. In the Palisades sill the edges at top and bottom were quickly chilled to basalt or basaltic glass. The first minerals to crystallize were magnetite and chromite which settled to the bottom of the molten mass.

Olivine followed, and then pyroxene formed at the same time the plagioglass began crystallizing. At first the calcic members of the plagioclase series and then, as the chemistry changed, the more sodic plagioclase crystals formed. The magnetite and olivine rich layers in the Palisades, although thin, can be identified in the mass. The olivine band particularly stands out as a yellowish-brown layer which weathers with a rather sandy look. It can be observed in the cliffs at Fort Lee and at other points along the cliffs bordering the Hudson in the central area of the sill. If the sill had been at least half again as thick, New Jersey might have had chromite mines, similar to those worked in the great sills in Montana and Africa. In any event, the bands of crystals, which settled out of the cooling liquid by gravity, are visible in the Palisades sill and demonstrate the interesting and complex chemistry of a thick mass of cooling magma.

The bulk of the mass is the interlocking network of feldspar and pyroxenes. The diabasic texture indicates not only that the plagioclases formed earlier than the pyroxenes but also that the melt contained more than the usual amount of plagioclase feldspar molecules. In the final stages of cooling a highly aqueous and siliceous solution was left in the unsolidified part of the mass. This rock, sometimes called a granophyre, has a composition which is very close to that of a granite and is frequently red in color because of its orthoclase feldspars. Such a reddish granophyre can be found on the dumps of the Griggstown copper mine.

Both the lava flows and the intrusives produced copper deposits. For rather obvious reasons the copper deposits of the lava flow are found in the lava or in the underlying sandstones (Chimney Rock and American mines). Native copper is the most spectacular mineral find but concentrations of other copper minerals are common. None of the numerous occurrences have ever been really worked as producing mines. The grade of ore is just high enough to entice development but not high enough to permit a profit.

The Victoria, or Schuyler, or Arlington mine has been of unusual historic interest since it first began producing copper between 1693 and 1710. This mine with the one at Griggstown, which first produced sometime between 1753 and 1810, are perhaps the best known New Jersey Triassic copper deposits. In both mines copper-bearing solutions from basalt or diabase dikes which are apparently off-shoots of the Palisades sill precipitated copper minerals in the overlying sandstones and shales. Copper mineralization has been found at many other locations adjacent to or in the Triassic intrusives and lava flows from Pompton and Arlington on the north through Plainfield, Somerville, and New Brunswick to Pennington and Flemington on the south.

New Jersey is well known in mineralogical circles because of its zeolite and related traprock minerals. The minerals themselves are extremely showy and therefore popular with collectors. Many fine collections of New Jersey zeolites are found throughout the world. Some of the larger and better specimens were gathered when the several railroad tunnels were being driven through Bergen Hill to connect the Hudson River waterfront with the rest of the state and nation. Quarry operations and new construction are continuously watched by mineral collectors, and a few good finds are made each year.

In addition to the previously mentioned copper and chromite there are some seventy minerals which have been found in veins and openings in the basalt flows, diabase intrusives, or in the adjacent metamorphic rocks. Eleven of the twenty-six true zeolite minerals (hydrated alumino-silicates), of which prehnite, pectolite, and apophyllite are the best known and most common, are found in the New Jersey traprocks.

The cavities oı negative crystal forms of minerals which have been dissolved away are common enough in the Paterson and Upper Montclair area of the First Watchungs to have been noted by collectors. These cavities of former crystals of glauberite and anhydrite indicate that the lava flows poured out across areas of

saline (argillite area) lakes. The aqueous solutions from the lava became contaminated by and saturated with calcium sulphates from the lake waters. This contamination altered the complex chemical sequence in which the various minerals were formed in the very last stages of cooling of the basalt, with the resulting growth of glauberite and anhydrite crystals.

A serpentine mass at Castle Point, Hoboken, should be noted. The serpentine, brucite, dolomite, and hydromagnesite reported found at Hoboken come not from the Palisades but from the serpentine mass which here is an alteration product of an ultrabasic intrusive plug of peridotite. A similar and larger plug is found on Staten Island. Serpentine, however, can also come from the hydrothermal alteration of marble. This last type of serpentine is found in the Highlands and is actively worked for decorative stone near Phillipsburg.

The mid-state area underlain by Triassic rocks is unusual in a geographic sense in a number of ways all of which can be attributed to the qualities, location, and erosion resistance of the several rock types. It is also the only area of the State in which each of the geologic formations is still used as an ore. New Jersey, as has been noted, leads the nation in the production of diabase and basaltic type traprock; moreover, the Stockton sandstone and, to a lesser extent, the argillite are desirable building stones which are still used, and the Brunswick shale is utilized near Somerville for the manufacture of sewer tile.

The diabase and basalt ridges which rise above the red shale lowland have channeled and guided the growth of the State because they have been barriers to transportation. During the Revolutionary War, the British did not penetrate the arc of the Watchungs or the Hunterdon Plateau and exercised only nominal control over the Triassic basin north of Hackensack, but went to great lengths to retain control of the Newark-Elizabeth-Amboy area and thus of the central Jersey corridor between the Hudson and the Delaware.

The Palisades, low only at Bayonne and breached by waterways only at the Arthur Kill and Kill van Kull, have been a barrier to westward communication from, and to the growth of, the port of New York. Engineering and technical progress have reduced but not eliminated the effect of this barrier upon the east-west movement of people and goods. First, there was the construction of tunnels through the Palisades ridge. Later tunnels and bridges were built not only to cross the ridge at a level below the crest but the river beyond. The Bergen Hill tunnels, the Morris Canal, the trolley inclines and elevators—rather puny engineering works by today's standards—were in their time advanced and imaginative solutions to the problem of moving commuters across the Palisades wall to the ferry boats which crossed the Hudson moat.

The water routes around the end of the Palisades have been both a blessing and a problem. Newark, Elizabeth, and the port facilities bordering Newark Bay and Staten Island have grown along some of the shore. The northern end of Newark Bay is the partially reclaimed Hackensack Meadows. This swamp area, teeming with birds and muskrat, is less than five miles from the world's most densely populated island and its international center of finance. Economics has not yet permitted engineers to reclaim the area for commerce although efforts and proposals have been made since the middle of the nineteenth century. This swamp, as with others in the Triassic basin underlain by shale, results from a combination of rapid post-Triassic erosion of the Brunswick shale and several ice-age conditions which have not yet been modified by post-Pleistocene erosion and changes in sea level.

The sandstone areas and parts of the shale areas in the basin proved from earlier Colonial times to be more fertile than much of the Coastal Plain or the higher ground underlain by basalt or argillite. Many of the latter areas are still forested today. Farms, villages, and relatively good roads were developed across the red shale

lowlands from the earliest times. The Palisades, its extension from Rocky Hill to the west, and the Watchungs channeled development and population growth into the valley from Somerville and New Brunswick to Paterson and Hackensack. At Paterson the only water gap in the Watchung ridges gave that city the abundant water power needed at the beginning of the industrial revolution. Trenton had water power because of the wedge of Precambrian rocks bordering the Piedmont. The town of High Bridge, where the south branch of the Raritan spills out of the Highlands into the Triassic basin, also had easily developed water power. These two cities and the town became the sites of some of the earliest forges, mills, and heavy industry in the State.

Paterson, Mahwah, Suffern, Sparkill, Morristown, Short Hills, Summit, Newark, Elizabeth, Bayonne, Perth Amboy, New Brunswick, Somerville, Clinton, Lambertville, Hopewell, Princeton, and Trenton—each has an interesting history of transportation development by road, rail, or canal because each is at a low level exit from the central Jersey Triassic basin or at a water gate for commerce whether it be ocean or river. If basalt, diabase, and argillite had been less resistant to erosion or the shale and sandstone harder and more durable, the geography and development of the State would have been a very different story. The areas of the Triassic basins in eastern North America have rich soil, are well watered, and have a subdued topography which conditions have given them history, wealth, and importance far greater than that of the rest of their own Piedmont or the other bordering Physiographic provinces.

V

MISSING EVIDENCE—THE JURASSIC
(185 to 140 million years ago)

OF THE FOUR GEOLOGIC PERIODS missing from the New Jersey stratigraphic record the events of Jurassic time are the least known. The missing geologic record for the Mississippian and Pennsylvanian periods, known in Europe as the Carboniferous period, can be projected into New Jersey without too much likelihood of error, because the truncated edges of strata belonging to these geologic periods are only a few miles west or northwest of our borders. It seems certain that at least part of the great Catskill delta, with its sandstones and shales, was deposited on northern New Jersey. Whether or not the coal swamps of the period extended into the area can not be determined.

The Permian rocks in western Pennsylvania are too far away to provide much information about what was happening in New Jersey. As the various crustal movements (disturbances) took place more and more frequently in the later part of the Paleozoic era, New Jersey received its share of crustal warping, compression, folding, and erosion of the upraised land masses. The folding and erosion of the Devonian and earlier rocks which are found in the great infolded valleys of the Highlands probably continued and was most severe during the Permian and the early Triassic.

By middle Triassic times shortening of the subcrust and the compressions of the crust, or the orogenic move-

ments called the Appalachian Revolution, had come to a close. We can think of northern New Jersey at that time as perhaps nearly equivalent to the Himalaya Mountains of today (Everest's top is shallow-water marine limestone of Cretaceous age), while the Catskill delta to the north and northwest would be the equivalent of todays Ganges plain. Whether or not New Jersey was once the roof of the world, and it probably wasn't really, there was a great deal of folding, uplift, and erosion as shown by today's steeply tilted and infolded sediments of Paleozoic age.

With the relaxation of the compressive crustal forces, the keystones of some of the arches dropped forming the Triassic basins which have just been discussed. It should be pointed out that there was in this time, between late Triassic and late Jurassic, still a great deal of Paleozoic limestone, shale, and sandstone covering what is now the Highlands. It is also important to note that in early Jurassic times most of the Triassic sediments, particularly those along the northwest border of the basin, were flat-lying or dipping to the south, quite different from the moderate northwesterly dip of today.

The Triassic sediments were deposited so late in the period that for a time they were believed to be Jurassic in age. However, there are no known Jurassic sediments in eastern North America. What happened during this 45-million-year period is unknown.

It can be assumed that it was a prolonged period of erosion and that no deposits were laid down. However, if there was erosion, the material must have been deposited somewhere; otherwise, it would have had to be carried in solution or suspension in the Jurassic seas for millions of years. Since this is unlikely, the next alternative solution would be to assume that during Jurassic times great river systems, like today's Mississippi, carried material far away from the area of today's North Atlantic states. Where and how all of this erosion could have taken place without leaving a trace of Jurassic deposits in the eastern United States is one of the great geologic

puzzles. It is such an enigma that few geologists care to speculate as to what may have happened. R. C. Moore suggests that the missing Jurassic deposits may be off to the east of the present coastline under the younger sediments of the continental shelf. Jurassic beds are exposed in Cuba, western South Dakota, Colorado, New Mexico, and Arizona. Jurassic rocks are also encountered in deep oil wells along the Gulf Coast from Alabama to Texas.

With nothing deposited in eastern or central North America, the Jurassic system in Europe, by way of contrast, is strikingly divided into the Lias or Black Jura, the Dogger or Brown Jura, and the Malm or White Jura, all with such an abundance and range of index fossils that many principles of stratigraphy were derived from studies of the European rocks.

Deep borings for oil, which has yet to be found, and for water, which can be abundant, in the New Jersey Coastal Plain indicate that the Jurassic and perhaps earlier erosion had beveled the pre-Cretaceous hard rocks to a wide region of low relief (about two hundred feet maximum) which is tilted gently seaward. This surface is nearly coincident with the present surface along the southeastern border of the Piedmont Province. Further inland, of course, it has been removed by subsequent erosion. Such a region of low relief is called a peneplain ("almost a plain"), and since this surface is exposed at the fall line (Trenton, New Brunswick, New York) it is called the fall-zone peneplain in some of the older geologic texts.

The writer prefers to ignore such peneplain terminology as the "basement," or hard rock surface beneath the Coastal Plain, which is getting a bit more rugged and less like a peneplain with each deep well which goes all the way down. The Jurassic, and if you will, the fall-zone peneplain, is, however, a great dividing line or time of change in the geology of New Jersey. All of the pre-Jurassic materials are hard rock. Nearly all of the younger (Cretaceous, Tertiary, and Pleistocene) materials are unconsolidated sediments. In local areas and

very restricted horizons, hematite, pyrite, and, perhaps at depth, silica and calcite cement some Coastal Plain beds. Lithified strata are rare and comprise only a small part of the stratigraphic column.

In the preceding discussion of the Triassic, mention was made of the border faults which apparently were active as the Triassic sediments were deposited. Mention was also made of faults which in west central New Jersey repeated the stratigraphic sequence in the main Triassic basin. These last mentioned faults may have developed in the very late Triassic, but because of the relationship of some of the basalt and diabase intrusions to the fault zone, the last movements on these faults must have been post-solidification of the intrusives in very late Triassic or early Jurassic times.

The folding of the flows and the sediments in the Hook Mountain and northern Watchung area and the tilting northwestward of the strata in the Triassic basin were also a later, and probably in part a post-Triassic, event. Actually, except for a few sections along the border fault, there is nothing to indicate that the faulting which repeats the Triassic section along the Delaware and the other crustal adjustments which tilted, folded, and faulted the Triassic could not have occurred at any time or times between the very late Triassic and the beginning of sedimentation during the upper Cretaceous.

The Sand Hill outlier of upper Cretaceous or later sediments is at the edge of the basin resting on the exposed edge of the Rocky Hill–Palisades sill. It provides only a vague upper limit of time, since the tilting and erosion must have been earlier. Detailed analysis of the structures and precise dating of the last crustal movements affecting the Triassic Basin are at present unsolved geologic problems.

At Beemerville, Sussex County, nepheline syenite with much finely dispersed pyrite is found in a number of plugs and dikes intruding Ordovician but not Silurian sediments. Nearby, at Libertyville, plugs or basic volcanic breccia containing large and numerous fragments of the

intruded slate, limestone, and gneiss are also found. Because of evidence of Ordovician volcanic activity in New England and the Ordovician age of the peridotite (now altered to serpentine) intrusions of Hoboken and Staten Island, the Beemerville and Libertyville intrusions were for a long time believed to be Ordovician. Recent dating, by methods based on the decay of radioactive minerals, now indicate that the Beemerville and Libertyville intrusions occurred during the Mesozoic. One can only speculate as to where the surface was and what the volcano looked like as it ejected its fiery charge upon a land surface far above what is now called Sussex County.

The record of what happened in New Jersey during Jurassic times is missing, but we can be sure that much happened during the more than 45 million years between the last events affecting the Triassic basin and the deposition in Cretaceous times of the Raritan formation, the first and oldest Coastal Plain formation exposed at the surface of the New Jersey Coastal Plain today.

VI

SOUTH JERSEY BENEATH THE SEA

(140 to 70 million years ago)

FROM THE GRAND BANKS of Newfoundland to the Peninsula of Yucatan, the North American continent is bordered by unconsolidated Cretaceous and Tertiary sediments which underlie the Atlantic Plain Physiographic Province. North and east of New Jersey the bulk of the Atlantic Plain is submerged and is therefore a part of the continental shelf. The part of the Atlantic Plain north of New Jersey has in addition been glaciated, which thus, in another way, makes it different from the rest of the plain to the south. The terminal moraines of the continental glaciers and other related Pleistocene deposits have blanketed and capped the older sediments so that Long Lsland, Block Island, Martha's Vineyard, Cape Cod, and several minor offshore islands project above the surface of the sea. There is also a third difference between the northern part of the Atlantic Plain and the plain to the south. From the Potomac estuary northward an inner lowland has developed on the upper Cretaceous sediments which were deposited. This inner lowland is indicated by the Gulf of Maine, the low-lying narrow neck of Cape Cod, Buzzards Bay, Long Island Sound, the "so-called" inner Coastal Plain of New Jersey, the Trenton-Wilmington reach of the Delaware River, the head of Chesapeake Bay, and the Potomac River south of Washington.

In New Jersey and southward the Atlantic Plain consists of two parts: the submerged section or continental shelf and the emergent section or Coastal Plain. At the latitude of New Jersey the emergent part of the Atlantic Plain increases from the 24-mile-width between New Brunswick and Sandy Hook to a width of about 60 miles from Pennsville to Sea Isle City. As the Coastal Plain widens to the south, the continental shelf, about a hundred miles wide at the entrance to New York Harbor, narrows considerably off Cape Hatteras to a width of about five miles off Florida.

The Coastal Plain of New Jersey is generally considered to be the three-fifths of the land area of the State south of Lower New York Bay and the Raritan River estuary and east of a line which runs from New Brunswick to Trenton and then down the west side of the Delaware River to Wilmington. Actually a small segment of the Coastal Plain with Cretaceous sediments capped by Pleistocene deposits, as is the case on Staten Island and Long Island, is found east of Metuchen on the north side of the Raritan River estuary from Piscataway through Keasbey and Fords to Perth Amboy and Chrome. This northernmost glaciated part of the Coastal Plain, with an area of about twenty-five square miles, has a geologic history which more closely resembles that of Long Island than the rest of the New Jersey Coastal Plain to the south.

The New Jersey Coastal Plain has many of the features and geologic formations found in the Coastal Plain segments of the states to the south. New Jersey, however, has one very distinctive topographic and geologic feature not found to the south, a cuesta formed by the upper Cretaceous sand and marl formations. This cuesta extending nearly east-west and overlooking New York Harbor from the south between Atlantic Highlands (the Highlands of the Navesink, elevation 235 feet) and Beacon Hill (elevation 373 feet) in western Monmouth County, swings to a southwesterly direction between Englishtown and Freehold, continues southwestward to the

west of Fort Dix, and passes through Arney's Mount, Mount Holly, Mount Laurel, Woodbury Heights, and Mullica Hill. The Coastal Plain is divided by this cuesta into two segments which the geographers call the Inner Coastal Plain, the lowland north and west of the cuesta's steep slope with drainage to New York Bay, the Raritan, and the Delaware, and the Outer Coastal Plain, the cuesta's very gentle other slope, with drainage to the Atlantic or, in the south, to Delaware Bay.

Geologically the two parts of the Coastal Plain are not very different. Unconsolidated clays, sands, marls, and gravels are found in both areas. There is a greater proportion of clays in the sediments of the Inner Coastal Plain while the topmost formation, the Cohansey, exposed at the surface of most of the Outer Coastal Plain, is usually a well sorted porous sand. Geographically, the differences between the two parts of the Coastal Plain are extreme. As mentioned above, the Coastal Plain encompasses about three-fifths of the land of New Jersey. Within this area is about one-fourth of New Jersey's population. Over two-thirds of these people live in the area of the Inner Coastal Plain on the clay lowlands between Trenton and New Brunswick or along the south side of the Delaware River. The bulk of the remaining third of this one-quarter of New Jersey's people live in the seaside resorts along the coast. Over one-half of New Jersey's forested area is found in the Coastal Plain and over two-thirds of this is found on the sandy soils of the Outer Coastal Plain. Within the area of the Cohansey formation outcroppings is the nearly uninhabited one-quarter of New Jersey called the "Pine Barrens." Only with today's knowledge of what is needed to form soil, and our improved agricultural methods, are the Pine Barrens beginning reluctantly to receive an increasing number of farmers and residents. Until now most of the gardens of the Garden State have been within the area of the Inner Coastal Plain and the Triassic lowlands.

The Coastal Plain had its beginnings in Cretaceous

times when the sea began to encroach upon what is now the southern New Jersey area of Cumberland, Cape May, and Atlantic counties. The older or lower Cretaceous formations are found in this part of New Jersey only in deep wells, although the formations reach the surface in Maryland and Virginia. In the second half of Cretaceous times, the Raritan formation was being deposited upon all of what is now the area of the New Jersey Coastal Plain and also upon areas to the north and west where the Triassic rocks of central Jersey and the Precambrian and Paleozoic crystalline rocks of Trenton, Philadelphia, and Wilmington are now exposed.

The depth and nature of this older rock surface upon which the Cretaceous sediments were deposited is known only from the few deep wells or, less definitely, from interpretations of geophysical exploration made either by the recording of artificial earthquake waves (seismic profiles) or by the precise measurements of the earth's gravitational attraction (gravity maps). In Camden and Mercer counties wells and geophysical studies both indicate that the surface, although generally very flat, has a relief in some places of nearly two hundred feet and is cut by shallow stream valleys much like those found in central New Jersey today. This rock surface, sometimes called the "basement" because most of the rocks are Precambrian in age, or sometimes the fall-zone peneplain because it reaches the present surface along the line of falls where the rivers from the Piedmont start across the Coastal Plain, deepens toward the ocean at a rate of from 80 to 100 feet per mile. At Island Beach it is 3793 feet below sea level. In southern Cape May County it is 6407 feet below the surface. Here, however, the lowest twelve hundred or so feet of Cretaceous sediments have become lithified and are hard sandstones and shales.

Upon this ancient pre-Cretaceous surface there are piled, like the layers of a cake, between 14 and 24 "formations" of unconsolidated clays, sands, marls, and gravels. By definition a formation is a mapable unit of rocks or sediments. Most of these formations are com-

posed of distinctive types of sediments and many have identifying fossils not found in other formations. In thickness the layers range from thin formations with maximum thicknesses of 11 feet, 20 feet, or 25 feet up to thick formations like the Raritan, Kirkwood, or Cohansey which in some areas exceed 250 feet. There are at least three formations in southeastern New Jersey which are not exposed at the surface, and at the top of the pile like frosting on a cake are four "formations" of Pleistocene yellow gravels. One of these gravel formations may actually be pre-Pleistocene in age.

The analogy of a layer cake for the Coastal Plain formations should be used with a great deal of caution. The lithology and thickness of most layers change from north to south, from east to west, and from the surface to where it is found in depth. Most significantly these changes frequently occur vertically within the layer or formation itself. The order of deposition may be quite different from one part of the formation to another. The seven rather distinct members or types of sediments of the Raritan formation found in Middlesex and Monmouth counties cannot be traced southward so far as Trenton. In some areas the Raritan cannot be distinguished from the overlying Magothy formation. In other areas it seems identical to the underlying Patapsco and Patuxent formations. The Cohansey formation, on the top of the heap, is worked for clay at Winslow Junction, for its very pure quartz sand in Cumberland County, for its limonite cemented building stone near Vineland, and for its heavy minerals and gravel near Lakewood. The Red Bank and Tinton formations pinch out to the southwest and thus are best exposed in Monmouth County. The Vincentown is sandy in Monmouth County, very calcareous in Burlington County at the type locality, and sandy again in Salem County. With the many variations in the character or thickness of the formations, the presence of fossils, and the changes in the character of the sediments indicating a change in origin, the presence or absence of distinctive sedimentary

features such as specific minerals, heavy mineral suites, wood fragments or concretions and the precise description of the character of the sediments become very important as aids in deciphering the geologic records.

Like all geologic formations those of the Coastal Plain are named after the locations of the exposures which were first described and which therefore have the most typical lithology. The Coastal Plain formations, however, are unfolded, flat-lying, and, since they are also in an area of low relief, often poorly exposed. Samples taken from wells drilled in the Coastal Plain become a valuable and essential source of information. The distinctive minerals, the sedimentary sequences, and the microfossils revealed by wells and test borings must be utilized whenever possible to assure accurate correlation between the formation as exposed at the surface and as found at depth in the wells. Wells are also relatively more important in deciphering the Coastal Plain geologic history because the sands are both porous and permeable even at great depths and some water wells are therefore drilled quite deep.

Seven deep wells in various parts of the Coastal Plain have been drilled to prospect for oil. The geologic age of the formations, Cretaceous and Tertiary, is the same as the formations from which oil and natural gas have been extracted along the Gulf Coast. Oil has not yet been found in New Jersey. However, as the Coastal Plain sediments are studied and restudied, the necessary clues about the subsurface may be developed and lead to such a discovery either in southern New Jersey or offshore on the continental shelf. From these very deep wells great thicknesses of the Coastal Plain formations may be studied as single units and many of the changes in the formations plotted on maps.

From early Cretaceous times until the present as sea level has changed, or as the earth's crust beneath New Jersey has gone up or down, the ocean has moved north, northwest, or west across New Jersey to and beyond the western limits of the Coastal Plain or has retreated south

or east far offshore to the edge of the continental shelf. The sediments reveal not only these alternating periods of deposition and erosion but also the depth of water and approximate location of the coastline. Each time the sea retreated and erosion took place, part of the record was removed and an unconformity developed between the older sediments and those deposited by the next transgression of the sea upon the land.

While the area involved in these changes from land to sea bottom and back to land are great, the vertical change in sea level may actually be quite small. If the ocean were to rise one hundred feet, the Coastal Plain would be reduced to two large islands: one centered on Elmer, Clayton, and Williamstown; and the other in the north on Monmouth and Ocean counties. Shallow straits or sounds would connect Philadelphia to New York, through Trenton and New Brunswick, and Burlington to Atlantic City. On the other hand, if the sea level were to drop one hundred feet, rapids would form in the Delaware River off Cape May and the Atlantic City boardwalk would be at least thirty miles inland from the new beach resorts.

Although each of the Coastal Plain formations, from the Raritan on the bottom of the heap to the Cohansey at the top of the pile, immediately beneath the largest part of our present surface, is discussed in this chapter, it should be remembered that with the withdrawal to the east of the Cretaceous seas (post-Tinton sandstone), erosion took place over all of what is now New Jersey. This period of erosion, until the sea again returned, depositing the Hornerstown formation in Paleocene times, is marked by an unconformity which is one of the most significant geologic features in the Coastal Plain. The projection of the plain of this unconformity at the base of the Hornerstown (Tertiary-Paleocene) northwestward beyond the Coastal Plain coincides very closely with the flat tops of our various mountains in northern New Jersey, suggesting that the present topography of northern and central New Jersey has developed from the

removal of the softer materials during Tertiary times, thus forming most of our preesnt valleys. These Tertiary deposits are therefore, at least in part, composed of material removed from northern New Jersey by erosion and deposited in the area of the southern New Jersey Coastal Plain. The significance of these events will be elaborated upon in the next chapter, as they explain the beginnings of the formation of our landscape. The characteristics of the six Tertiary formations and the deposition of three to five hundred feet of Tertiary sediments in Monmouth and Burlington counties and nearly two thousand feet of Tertiary sediments in Atlantic and the other southern counties is most conveniently described here.

The Raritan formation, named for its exposures along Raritan Bay, is perhaps the best known and most important Coastal Plain formation in New Jersey. In the earlier works and on the present geologic map the Raritan and the overlying Magothy formation are treated as one formation: the Magothy-Raritan, or more properly the Raritan-Magothy.

The Raritan formation consists of 150 to 300 feet of rapidly alternating lenses of light-colored white or yellow sands and white-cream or light gray clays which may also be dark gray or red. The Raritan in its exposures, and in most downdip areas, is a non-marine flood plain deposit. At a few places, more frequently to the east or south, well samples indicate that the Raritan is marine. A plesiosaur bone, several footprints of a large dinosaur found in the clays at Woodbridge, a few brackish water pelecypods, and an abundant flora of nearly modern plants constitute the fossil assemblage of this formation. To the south in Delaware the contacts and differences in lithology between the underlying early Cretaceous, Patapsco, and Patuxent formations are so indistinct that the formations can only be separated by the differences in the suites of heavy minerals.

The Raritan in the Raritan Bay area can be divided into four clay and three sand members. The overlying

Magothy is nearly 175 feet thick and separated by a disconformity. Near Trenton the various sand and clay members of the Raritan can no longer be identified. The overlying Magothy, reduced to a thickness of 25 to 30 feet, can no longer be distingushed. In Delaware the Magothy is sometimes missing and where found is an obvious transitional formation from the non-marine Raritan to the post-Magothy Cretaceous marine clays. In short, the sediments of the Raritan formation and its relationships to the formations above and below indicate that during Cretaceous times in New Jersey the sea was encroaching upon a coastal plain and advancing farther and farther to the north and west.

The importance of the Raritan formation, in its outcrops from Raritan Bay southward until it passes into the state of Delaware, as well as in its subsurface occurrence in Monmouth, Ocean, Burlington, and Camden counties, to the growth and industrial development of the Inner Coastal Plain can hardly be overemphasized.

Its clay beds are still worked around Sayreville and South Amboy. Once also worked around Trenton and as far west as Camden, they provided the raw materials for bricks, terra cotta and, for a time, the porcelain and pottery industry for which New Jersey is now so well known. New knowledge of clays and their ceramic properties has changed the sources of supply for much of Trenton's pottery industry but terra-cotta products and bricks are still being made from Raritan clays.

The sand beds and lenses of the Raritan formation are perhaps the most important single aquifer within the state. Most large industrial wells and public supply wells from South Amboy southwest to Paulsboro and Pitman tap the Raritan sands. North of the Raritan River smaller supplies are secured for some industries around Perth Amboy. At the south end of the belt of Raritan outcroppings in New Jersey, south and west of Gibbsboro, wells to the Raritan are not so successful as those farther north probably because of an increased clay content. East of the surface exposures the Raritan

is the principal and frequently the only source of water for large industrial or public supply wells. In eastern and northern Monmouth County it is the main source of ground water. Without the bountiful water supplies from wells giving five hundred, one thousand, or sometimes even fifteen hundred gallons of water per minute, many industries and towns from Sandy Hook to Pennsville could not survive and prosper. Even today, however, the understanding of engineers and industrialists about underground water in general, and this formation in particular, is so slight that overpumping of the fresh water supplies has drawn the salt water of Raritan Bay and the poor quality Delaware River water into many shallow wells drawing from the Raritan formation.

The Magothy formation, a relatively thin series of alternating dark clays and fine white sands characterized by charcoal fragments or carbonized fossil wood, is of great interest. It is thickest along the shores of Raritan Bay. The carbonized wood is found in both the clay and sand beds. Forty-three species of marine invertebrate fossils and an abundant flora composed of even more modern plants than those found in the Raritan have been recovered from the Magothy formation. All of these fossils indicate that the Magothy formation was deposited in the swamps and estuaries of an advancing sea. The rising sea level caused the rivers on the land to the west and north contemporaneously to deposit sediments. These fluvial sediments would now be described as part of the Raritan formation if they had not been removed by erosion.

Most mineral collectors know of the pyrite and marcasite concretions found in the Magothy formation at Cliffwood Beach on Raritan Bay. Well-drillers and geologists recognize the clean white sands with charcoal as being from the Magothy formation and so continue drilling for the better water-bearing sands of the Raritan below. A few well-drillers and geologists can recognize the change in conditions of deposition by the tiny red to

brown siderite nodules which mark the unconformity between the Magothy above and the Raritan below.

The Merchantville clay, about sixty feet of highly fossiliferous black, glauconitic micaceous marine clays, rests unconformably upon the Magothy formation. Once extensively worked, it is still utilized for brick clay at a few places. Shark teeth, turtles, and fish vertebrae and a wide variety of distinctive invertebrate fossils have been found in the Merchantville clay formation.

The Woodbury clay is about fifty feet of non-glauconitic black marine clays which weather to a brown color. It rests conformably upon the Merchantville clay. The lack of glauconite, the chocolate-brown weathering characteristics and a very different fossil fauna distinguish the Woodbury clay from the underlying Merchantville. A reproduction of the skeleton of a large duck-bill dinosaur (*Hadrosaurus*) found in this formation near Haddonfield about one hundred years ago is now on display at the New Jersey State Museum in Trenton.

The Woodbury and Merchantville clays suggest that the sea had caused a maximum submergence of New Jersey during this part of Cretaceous time. The next formation, the Englishtown sands, suggests a partial withdrawal or at least more shallow waters nearer shore.

The Englishtown formation is a distinctive white to yellow quartz sand which decreases in thickness from 140 feet in Monmouth County to a thickness of only 20 feet in Gloucester County. It conformably overlies the Woodbury clay and may represent non-marine conditions. Only a few shell fragments have been found in this formation. South and east of its surface outcrops, the sand may be a source of moderate supplies of ground water in the northern part of the Coastal Plain.

The Marshalltown formation, a black micaceous sandy clay in the north and a glauconitic fossiliferous clay marl in the south, is from 30 to 40 feet thick and extends a little farther south (Salem County) than the conforma-

THE HADDONFIELD DINOSAUR

This is a cast of the skeleton of HADROSAURUS FOULKI, the first complete dinosaur skeleton known in North America. The bones of this duck-bill form of Trachodon dinosaur were found in the Woodbury formation in 1858 near Haddonfield.

New Jersey State Museum

bly underlying Englishtown. A marine formation, it indicates a re-advance of the sea across the Cretaceous Coastal Plain.

The Wenonah and Mount Laurel sands can hardly be distinguished one from the other by differences in the sediments. The fossil content of each formation, however, is very different. Each formation and its assemblage of fossils is represented by a much greater thickness of sediments, which also have the same distinctive fossils, in the Coastal Plain of Maryland and to the south. There is some disagreement as to where the stratigraphic boundary between formations and the geologic age of the formations should be put. These formations perhaps more than most stratigraphic units, illustrate the difficulty man has in trying to classify and sort the elements of the natural world. Within this 40 to 80 feet of fine micaceous sands, with some glauconite in the upper part, there was a marked change in the character of the marine life that inhabited the sea. The fossils indicate that the sediments of the lower part belong to the Wenonah formation. The sediments of the upper part of the formation were deposited when the Mount Laurel formation was laid down in other areas.

To the south in Delaware the Mount Laurel formation is not divisible from the overlying Navesink formation. In New Jersey the Navesink is from 25 to 40 feet of gray glauconitic, sandy clay. At times the clay is green in color from the high percentage of glauconite grains which are present. The formation is rather well known to fossil collectors for its oyster shells (*Exogyra cancellata*) and its "fossil cigars" (*Belemnitella Americana*), the internal skeleton of a relative of the modern squid. These and other fossils in the "*Cucullaea* fauna" indicate a return to shallow-water conditions. The entire fossil assemblage has some of the characteristics of both the Mount Laurel below and the Navesink, but a number of fossils are found only in the Navesink.

The two overlying Cretaceous formations, the Red Bank and the Tinton sandstone, are found only in the

northern part of the Coastal Plain in Monmouth and bodering counties. If once deposited further south, the formations were later removed by erosion in early Tertiary times so that in the north the Hornerstown marls rest unconformably upon the Tinton, then on the Red Bank, and further south upon the Navesink.

The Navesink grades upward into the overlying Red Bank formation, a dark gray-brown micaceous sandy clay which becomes in its upper part a red to yellow-brown sand whose outcroppings on the banks of the Navesink River gave the town its name. Some 130 feet thick near Red Bank, the formation has been removed by erosion south of Sykesville in northeastern Burlington County. Fossils are found only in the lower clay beds of the formation. The evidence of fossils and heavy minerals suggests that the Red Bank formation was deposited in shallow water in the very last part of Cretaceous times.

The Tinton sandstone is the youngest of the Cretaceous formations in New Jersey. Fossils are rare and usually restricted to poorly preserved casts and molds with the shell material replaced by the blue phosphate mineral vivianite. The greenish-brown glauconite sands and clays are well indurated, forming the waterfall at Tinton Falls. Rounded blocks of these well cemented sands are found in the base of the overlying Tertiary Hornerstown marl separated from each other by wide crevices filled with the overlying material. This suggests that the sand had been cemented before erosion of the Tinton surface took place in early Tertiary times. The formation is not differentiated from the underlying Red Bank on the geologic map. Only about twenty feet thick, with every indication of having been deposited in very shallow water (fossils of crustacean claws and a *Cucullaea* fauna), the formation is important because it is part of the ridge-forming group which caused the previously mentioned cuesta of the Atlantic Highlands and the various mounts and heights between the inner and outer Coastal Plain.

It would seem appropriate, before discussing the Ter-

tiary formations, to again mention the important unconformity at the base of the Tertiary. It not only cuts out the Tinton, the Red Bank, and part of the Navesink formation but also is the erosional surface upon which the Hornerstown marl is deposited. The surface when projected northward almost coincides with the Schooley peneplain surface marked by the flat tops of northern New Jersey ridges.

It should also be pointed out that the fossils used to identify the formations are not always easy to find. They are found, however rarely, at locations from New Jersey all the way to Texas and thus permit the correlation of sedimentary formations over great distances. Some fossils, however abundant and easy to find, may not be restricted enough in their range through geologic formations and geologic time to be significant to the geologist, except as they may or may not indicate an ancient beach, a reef, deep water, or the evolution of some life form.

The six Tertiary formations of the New Jersey Coastal Plain can be divided into two groups: a Paleocene and Eocene or early Tertiary group of four relatively thin (100 to 180 feet) formations, the Hornerstown, the Vincentown, the Manasquan, and the Shark River; and a late Tertiary (Miocene and/or later) group of two thick (200 to 350 feet) formations, the Kirkwood and Cohansey.

The Hornerstown marl, a 30-foot thickness of glauconite with clay and sand, extends across New Jersey from near Atlantic Highlands through Freehold, Hornerstown, Birmingham, Mullica Hill, Sewell, and Woodstown and thence southward into the Delaware and beyond. A deep-water marine formation with relatively abundant fossils of indestructible sharks' teeth, vertebrae, and spines, it has occasionally given up bones and partial skeletons of turtles or crocodiles. In southern New Jersey, where the Red Bank and Tinton have been removed, the marl rests upon an earlier marl, the Navesink, from which fossil bones of marine reptiles have been recovered. Once worked at a number of localities the green-

sand was useful as a soil conditioner, and in the manufacture of water softeners. The introduction of agricultural chemicals and plastics has provided cheaper, more reliable substitute materials to the detriment of marl pit operations. For many years New Jersey has been the sole producer of greensand marl. As of late 1963 only one marl pit is still being worked. The most recent work on the age of the formation suggests that it was deposited in the Paleocene, although the earlier works and the geologic map assign the formation an Eocene age. The uppermost Hornerstown greensands grade upward across a comformable and transitional contact to the quartz sand or calcareous sand beds of the Vincentown formation.

The Vincentown formation is from 25 to 100 feet thick and usually composed of light-colored sands with some glauconite. Early workers included the lower glauconite and quartz sand beds with the underlying Hornerstown. The quartz sand is abundant in Monmouth and Salem counties, but in the central part of the outcrop area around Vincentown the formation is a light-yellow calcareous sand consisting almost entirely of fragments of bryozoan and complete foraminifera. The formation is so well known for its microfossils that the presence of larger-sized fossils such as brachiopods, echinoidea, crinoids, annelida, mollusca, crustacea, and ostracods are not usually noted.

The Manasquan marl (the "ash marls" of the early reports), a 13- to 17-foot formation of glauconite, fine quartz sand, and gray clays, is found above the Vincentown. Exposures are rare and it is sometimes grouped with the overlying Shark River marl.

The Shark River marl has a very limited area of outcrop near Long Branch and Farmingdale in Monmouth County. An extensive molluscan fauna has been described, but surface exposures of the 11-foot-thick formation are rare. Wells indicate that the formation thickens to the south beneath the surface. Both the Manasquan and Shark River marls are of Eocene age.

A major unconformity exists between the Eocene Manasquan and Shark River formations and the next overlying formation, the Miocene Kirkwood. In wells in southern New Jersey fossils have been recovered from sediments which suggest that a younger Eocene formation is present above the Manasquan. No fossil of Oligocene or of early Miocene age have yet been found in New Jersey. This suggests that during much of middle Tertiary time all of New Jersey was dry land. This unconformity, like that at the base of the Tertiary, also probably represents a time in southern New Jersey when much of the present topography in northern New Jersey was forming.

The Kirkwood formation is a sparsely fossiliferous, fine, micaceous quartz sand with black lignite and drab-colored clays. This marine formation, which is some 180 feet thick at the surface, is nearly 600 feet thick under Atlantic City and Cape May. Indicative of a transgression of the sea upon New Jersey in Miocene times, it changes upward over a few feet of transitional or reworked beds into the Cohansey formation. Emergence must have occurred in post-Kirkwood times so that the streams which deposited the Cohansey could rework the top of the underlying Kirkwood formation.

The Cohansey sands cover the largest surface area of the Coastal Plain. The formation is distinguishable from the underlying Kirkwood by its light color. It is a nonmarine white to yellow sand with laminae and at times sizable lenses of clay. Scattered pebbles or even thin lenses of gravel are also found in some areas. Some obscure mollusks, useless as index fossils, and perhaps some plant remains of possible Miocene age found near Millville are the only fossils ever found in the Cohansey. It is quite possible these plant fossils were derived from the underlying Kirkwood. At the top of the Coastal Plain heap, the bottom of the Cohansey dips seaward at a rate of 9 to 10 feet per mile, but the dip may increase to the southeast because the formation in some wells exceeds the 250-foot thickness computed from the pro-

jection of this dip seaward beneath the Coastal Plain. It has been suggested that the Cohansey is the non-marine equivalent of the Yorktown formation, a Miocene fossiliferous marine sand which looks very much like the Cohansey but which is not found north of Virginia. The variety of lithologies in the Cohansey, mentioned earlier in this chapter, suggests that the Cohansey can in the future be divided into either new formations or at least into members of a very thick formation.

The Cohansey formation is vital to the economy of southern New Jersey's outer Coastal Plain. The formation is not only an important source of water but is also the source of several mineral commodities. Glass sand in southern New Jersey, building stone near Vineland, clay at Winslow Junction, and ilmenite near Lakehurst are all being worked or have been worked until recently. Wells everywhere in the Cohansey are usually successful at shallow depths. Industrial or irrigation wells giving more than 500 gallons per minute are not uncommon.

The actual surface formations over much of the Coastal Plain are yellow gravels and sands described as the Pliocene Beacon Hill gravels, and the Pleistocene, Pennsauken, Bridgeton, and Cape May formations. However, all of these formations are more properly related to Pleistocene or Ice Age events. It is also possible to present a fairly good argument that the Cohansey formation is not Miocene but Pleistocene in age. Further work in the inaccessible areas of the Cohansey occurrence may indicate that at least part of the formation is, if not marine, the beach and sand-dune deposits of near-shore.

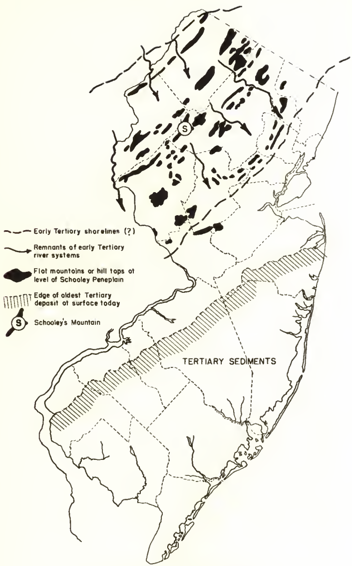
VII

OUR LANDSCAPE BEGINS

(70 to 1 million years ago)

OUR PRESENT-DAY LANDSCAPE north of the Coastal Plain is characterized by flat-topped ridges with a concordance of summit levels, which rise from a low level adjacent to the Coastal Plain to High Point, by valleys which usually follow the more easily weathered rocks, and by main rivers which cut across hard and soft rock alike in directions uncontrolled by any present-day geologic features. These primary characteristics of today's landscape are the logical result of erosion which has been nearly continuous in northern New Jersey since early Tertiary times.

In the Cretaceous, the sea was master over New Jersey. We can only speculate as to where the shore might have been. Both deep-sea and near-shore sediments, now preserved under the Coastal Plain, were apparently deposited upon at least part of what is now northern New Jersey. Some students of the evolution of the landscape (geomorphologists) believe the shore line in Cretaceous times may have been in the vicinity of today's Scranton and Wilkes-Barre. Crustal movements in late Cretaceous and early Tertiary caused a withdrawal of the sea and a raising of northern New Jersey that has not since been reversed. Before this uplift began, the land mass had long since been reduced to a flat, almost featureless plain over much of eastern Pennsylvania, New York, northern



TERTIARY NEW JERSEY
Tertiary sediments in New Jersey are chiefly marine. The oldest formations are deep water deposits.

New Jersey, and New England. Erosional remnants formed topographic lumps above this surface such as Mount Monadnock, New Hampshire, or the less pronounced higher peaks of today's Catskill Mountains. These monadnocks can be observed to the north of High Point, New Jersey, on a clear day, rising above the summit level of the Catskills and Poconos. Such a plain is known to geologists as a "peneplain" which signifies a surface leveled by prolonged stream erosion carried as close to sea level as the sluggish streams can cut and still flow. Monadnocks rise above this surface where the rocks are hard or where the main stream systems are far apart and have still not had time to reduce the area to the level of the generally flat surface. The present crest of Kittatinny Mountain, of the various ridges and mountains in the Highlands (including Schooleys Mountain), the Hunterdon Plateau, the Watchungs, the Sourland Mountains, the Palisades, and even the high ground around Princeton and north of Trenton have elevations close to the projected level of this original flat peneplain of New Jersey. At first, there may have been a veneer of Coastal Plain sediments above the deeply weathered rock across which the new streams of the emergent land flowed to meet the sea. Since the largest remnant of this summit level is the top of Schooleys Mountain, this surface is called the Schooley peneplain. Because this peneplain surface can be projected under the Coastal Plain and seems to coincide with the Cretaceous-Tertiary unconformity, it is assumed that the peneplain was formed in the very late Cretaceous and very earliest Tertiary times. It can also be assumed that the flatness of this surface caused the streams to meander and shift as they flowed sluggishly across the veneer of sediments on their way across the peneplain to the sea, just as the Mississippi does today south of Cairo, Illinois.

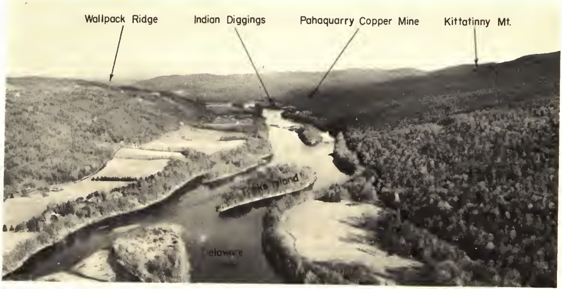
As crustal movements lifted northern New Jersey even higher, the Coastal Plain sediments and then the regolith (weathered rock) were removed down to the level of the harder underlying Precambrian, Paleozoic, or Triassic

rocks. When the loose material had been removed and the rivers encountered hard rock in their beds, they could not change course because erosion must grow upstream from the downstream end of the drainage. Rivers cannot climb out of their banks in order to follow a course along the areas of softer rocks.

Today, Delaware Water Gap, Wallpack Bend, the meandering course of the Delaware from Easton to Milford across hard and soft rock, the meandering of the Pequannock across the Highlands from Stockholm to Pompton, all mark present-day sections of modern rivers which still follow the ancient course established by ancestral streams on the old Schooley Peneplain.

Culvers Gap, the valley of Spruce Run, the pass near Lake Hopatcong, the gaps at Paterson, Rocky Hill, and Sparkill, the filled gaps at Summit and Jersey City, and many other low gaps or passes in other ridges mark the course of ancestral streams whose drainage was diverted after they had been eroding away the harder rock barriers for thousands of even millions of years.

As major streams cut lower into the hard rock barriers, tributary streams more rapidly eroded the softer limestones, shales, or sandstones, or the more shattered rock along the lines of major faults. The Ramapo followed the border fault to capture a tributary of the Hudson; a branch stream of the Delaware followed limestone upstream from today's Delaware Water Gap to capture the headwaters of the ancestral Passaic or Raritan at Culvers Gap. The story of this stream piracy, of a tributary of one stream capturing the headwaters of another, is a long and interesting one which is actually still continuing. Some studies of this phase of geologic history have the Hudson flowing westward through the Sparkill and then the Paterson Gap and then turning southward to flow out of the Watchungs through the gap at Summit. The Raritan may once have been a mighty stream which flowed up the present Millstone and out to sea at Toms River. The Delaware may have once flowed down the Mullica, for stream piracy also occurred along the inner



VALLEY OF THE UPPER DELAWARE

Looking northeast along the upper Delaware Valley. The flat summits on the right horizon and in the far distance are part of the Schooley peneplain. Indian artifacts have been excavated from the gravel terraces, particularly on the Jersey (right) side of the river. The gentle right-hand slopes are formed by the beds of the High Falls formation. The steep Pennsylvania slopes on the left are an extension of Wallpack Ridge, indicated in the extreme left background.

New Jersey Department Conservation and Economic Development

edge of the Coastal Plain, as the clays and fine sands were more easily removed than gravel, marl, or "South Jersey sandstone."

That limestone, which is soluble, is more easily eroded than shale, which is not, is so true that it can be argued that the two levels of the flat-bottomed Kittatinny Valley are the result of the differential in the rate of erosion of limesone and shale. This explanation does not fit the conditions in the Triassic near Somerville where there are two general levels, and so some geologists believe there were three peneplane levels in New Jersey. Because the Hunterdon Plateau is at the summit level and is composed of the same rocks found at the two lower elevations to the south and east, this argument also has some merit. Like most events in nature, results depends on many variable factors. Of one thing we can be sure, each ridge, each valley, each hill, and each gap seen in today's landscape is the result of millions of years of erosion and many interactions of geologic processes actting on geologic materials through geologic time. Delaware Water Gap is not the result of a cataclysmic event or some stupendous flood which suddenly broke through the ridge, but rather it is the result of a slow but inevitable erosion of hard rock by a river which in this small section of its ancestral course has been trapped for millions of years.

The occurrence of the soft iron-stained and sometimes cemented sands of the Coastal Plain resting on a low ridge of basalt at Sand Hill on U. S. Route 1 east of Princeton is perhaps one of the greatest unsolved riddles of the geology of Cretaceous and Tertiary New Jersey. Badly weathered, without any fossils, it is mapped as an outlier of the Cretaceous Raritan formation. However, its sedimentary character, plus its elevation and location, which is completely isolated from the rest of the Coastal Plain formations to the south, make it possible, if one wishes to argue, to correlate this sand with the Raritan, or the Englishtown, or the Cohansey, or perhaps even the Tinton and possibly other formations.

Perhaps some day a geologist will find a fossil or develop a new technique that will provide the means for the irrefutable correlation of this outlier with some specific formation found in the Coastal Plain.

Pleistocene events have, of course, greatly changed many parts of New Jersey's landscape. The changes in the landscape that have taken place north of the terminal moraine are generally recognized. The modification of the landscape in central and northern New Jersey has generally not been enough to conceal, except in local areas such as Great Meadows, the Great Swamp, or the Hackensack Meadows, the topographic framework of our landscape which has developed since early Tertiary times. In southern New Jersey, the Pleistocene changes are more subtle. Those who have studied the Pleistocene events recognize that there has been a nearly complete reversal of topography.

No one can deny that our landscape is very old nor that changes in the terrain are very slow. It is a rather shocking geologic thought, when we are used to thinking of the oldest geologic formations as being on the bottom of the heap, to realize that the higher features of the New Jersey landscape are the oldest features and that the valley bottoms are the youngest and often the unfinished bits of the landscape.

VIII

ICE AND THE CHANGING SHORE
(the last million years)

THE NEW JERSEY LANDSCAPE today with its lakes in the north, the offshore bar with our famous beaches, and the commercially important, drowned river valleys which form Port Newark, Delaware Bay, and New York Harbor are all the result of the unusual geologic events which have taken place during the last million years of the Pleistocene or Ice Ages. Continental glaciation is a relatively recent idea. The full implication of Pleistocene events are very new and not yet fully deciphered or understood. The idea of great continent-covering Ice Caps has great popular appeal, but several equally important related phenomena are often overlooked or not adequately related to the events of the glacial epoch.

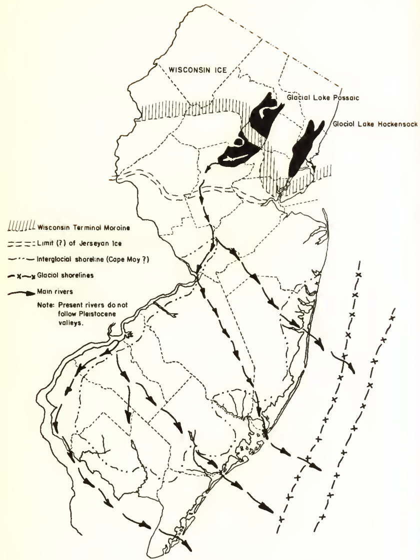
The name Pleistocene, meaning "most recent," was given by Sir Charles Lyell in 1839 to sediments in the Paris basin which had an invertebrate fossil assemblage containing 90 per cent or more of the invertebrate forms that are found living today. Lyell did not, at that time, give much consideration to the continental glaciation which had occurred during the period. It is perhaps fortuitous that the life forms developed during this geologic epoch with periods of unusually cold weather were sufficiently different from those of warmer times so that the name Pleistocene could later be used to encompass the time of continental glaciation. Pleistocene strati-

graphy is now based on the dating of glacial and interglacial ages which occurred during this last geologic epoch. The name Recent should perhaps be disregarded as all evidence indicates that we are still emerging from the last glacial episode, and, therefore, are still in the Pleistocene.

Most of the sorted and unsorted sand and gravel deposits found above the rock formations in many parts of the northern hemisphere were assumed at first to be the result of a catastrophic deluge or flood of marine waters which had "drifted" material from outside sources into places in front of, or on the sides of, the hills and mountains and across broad plains. The Pleistocene deposits were considered by many to be the evidence of the biblical Deluge. Even Lyell accepted the concept of erratic boulders and "drift deposits" as having been laid down by short-lived, widespread marine submergence.

In Cook's 1868 report on the "Geology of New Jersey" the Pleistocene deposits were referred to as the "drift gravels." The concept of continental glaciation advanced by Venetz, Agassiz, and Bernhardi between 1829 and 1837 had not yet been generally accepted by 1868. General acceptance of the concept of continental glaciation came slowly after Jamieson in 1862 and Geikie in 1863 published two papers, on the Scottish "drift" and glaciation, which proved that continental glaciation had occurred and that the "drift deposits" were not marine in origin or due to the Biblical flood but the result of this widespread glaciation. Scientific opposition to the idea of drifts being the result of continental glaciation did not die until about 1890.

In New Jersey, studies of the several glacial deposits were made in 1877 and 1878. A state-wide investigation made between 1890 and 1894 was published in 1902 as Volume V in the "Reports of the State Geologist," entitled *The Glacial Geology of New Jersey*. For its time it was a thorough, complete, and advanced treatise on the subject. More recent work has refined some of the data, solved some of the problems, and indicated the



ICE AGE (PLEISTOCENE) NEW JERSEY

need for restudy of some areas in the light of new concepts.

In 1902 it was rather important, in order to prove the concept of continental glaciation, to show that the Greenland Ice Cap covers an area nearly six hundred times as great as that covered by glaciers in the Alps, and that the four million square miles of North America covered by the Ice Age glaciers is only ten times greater in size than the Greenland Ice Cap. Two periods of glaciation were recognized and it was suggested that there might have been five periods of glaciations during all of the Pleistocene. In 1916 an effort was made to correlate the yellow gravels which cover much of central and southern New Jersey south of the terminal moraine with the glacial features to the north. All of this rather voluminous and careful work should now be re-examined against the rather complex frame of reference of our present and rapidly growing knowledge.

During the million years of Pleistocene time, masses of continental ice advanced southward from centers of accumulation in Labrador and south of Hudson Bay on four different occasions. The duration of each ice age when ice stood upon the land was actually much less than that of the periods between ice caps or interglacial ages. Of the four ages of ice advance, known as the Nebraskan, Kansan, Illinoian, and Wisconsin, three almost certainly reached into New Jersey. The most recent, or Wisconsin, advance extended farther south over more of the state than any of the earlier glaciations, so that the "older drift" of the earlier reports, found as scattered occurrences south of the Wisconsin moraine, is limited to an area west of Somerville and north of Flemington and Riegelsville. Most of this "older drift" is probably Illinoian in age, but the more southerly of the deposits probably are of Kansan age. Very little of the pre-Wisconsin history of New Jersey can be deciphered because of the deep weathering of the "older drift" deposits, the extensive erosion of this material from all but the higher

interstream ridges and the removal or burial of any earlier glacial features by the Wisconsin ice.

The Wisconsin age is subdivided into four sub-ages or re-advances of the ice. Each re-advance terminated farther north and farther away from the moraine of the oldest or Iowan sub-age ice. This prominent terminal moraine ridge, formed by the Iowan sub-age of the Wisconsin ice, extends across north central New Jersey from Perth Amboy to Metuchen, to Summit, to Morristown, to Dover, to Budd Lake, to Hackettstown, to Belvidere. The moraine of the next oldest Wisconsin sub-age or Tazewell ice, may have extended into New Jersey along the Kittatinny Valley as far as the Delaware River. The Tazewell ice apparently did not cover the New Jersey Highlands except in the vicinity of the Ramapo River and for a short distance south of Mahwah. Most of the deposits left by the Tazewell ice are, however, just north of New Jersey in New York State. The two youngest Wisconsin ice advances stopped well north of New Jersey in the vicinity of the Finger Lakes region and the Mohawk Valley. It was either some pronounced recessional moraines of the oldest Wisconsin or Iowan ice or perhaps the moraines of the Tazewell ice that suggested five ice advances to the early students of New Jersey's Pleistocene history.

With the acceptance of the theory of continental glaciation and the recognition that there were multiple glaciations, separated by long intervals of warmer climate and the virtual disappearance of glaciers from the surface of the earth, attention was given to other aspects of Pleistocene glaciations. The type of erosion and the deposits resulting from glacial action could be studied in the Alps and in other glaciated areas. Less obvious were related changes of sea level, lower than the present level at times of ice maxima and higher during interglacial ages.

A study of the larger Pleistocene lake systems led to the recognition of one of two other effects of continental ice caps. First it was found that where the ice is piled

thick above the surface, the land is depressed. Upon the removal of the ice, the land does not rebound as quickly as the ice is removed. Thus ancient shore lines of glacial lakes are now tilted upward to the north, 67 feet in 30 miles for Glacial Lake Passaic, but coastlines in northern latitudes and New Jersey are still submerged.

The second and least obvious effect is the very great change in weather conditions which occurred in front of the ice sheet. A tundra belt with frost heaving of the surficial deposits existed for miles in front of the ice mass. In these areas also, rapidly changing stream flows provided supplies of fine material and long dry periods so that the wind picked up the silt and fine material from the often dry river channels and deposited thick blankets of loess over higher ground. Finally, there still remains the problem of dating the ice advances. The amount of erosion which has taken place since the ice disappeared has provided a rough estimate of the time elapsed since the Wisconsin ice disappeared. The amount of sediments, such as varved clay, deposited on the bottom of a glacial lake provides a rough estimate of the time required for the glacial "retreat." Most recently radio-carbon dating has given rather precise time marks for a variety of glacial deposits from which a sequence of glacial events is being more correctly dated.

All of the above-mentioned features, problems, and methods are found or have been studied in New Jersey. The Pleistocene story is not just the story of the lakes, glacial deposits, and smoothed rock outcroppings in New Jersey north of the Wisconsin terminal moraine; but it is also one of the changing sea levels, changing coastlines, sinkings and risings of the earth's crust, of stream gravels and loess deposits south of the moraine, areas of rather remarkable Pleistocene deposition and erosion, and evidence of rapidly changing climate and life forms. The study of the Pleistocene is concerned not only with ice but also with weather, climate, streams, shore lines, topography, fauna and flora of the unusual and rapidly alternating environment of the last one million years.

The history of the changing conditions and examples of deposition or erosion resulting from the advance and "retreat" of an ice sheet can best be studied by examining the advance and retreat of the last great glacier to enter New Jersey, the Wisconsin ice.

As the Wisconsin ice advanced across New Jersey, it picked up loose or weathered rock and carried the material to the south. The larger rock fragments trapped in the ice acted like giant chisels or files, cutting scratches and grooves into the underlying solid bedrock. The direction of ice movement can be deduced from the direction of these scratches, striae, grooves, chatter marks, and friction cracks imprinted by the passing glacier on the bare rock outcroppings of northern New Jersey. Thus along the north-eastern end of Kittatinny Ridge the striae indicate that the ice moved west out of Kittatinny Valley over the ridge into the valley of the Delaware. Along the north-western end of Kittatinny ridge the ice moved to the southwest out of the Delaware Valley on the north side into Kittatinny Valley to the south of the ridge.

The direction of ice movement is also indicated by the location of the erratic boulders of unusual lithology. Thus fragments from the small area of outcroppings of the Beemerville nepheline-syenite intrusions are found between Kittatinny Mountain and Hewitts Ponds indicating a south or south-southwest movement of the ice from Beemerville. The orientation of the long axis of roche mountonnées, the smooth "northern" or stoss slope and the quarried and plucked "southern" or lee slope of rock ridges, as shown near Cranberrry Lake or Kittatinny Mountain or by the Palisades, and the rare isolated local remnants of preglacial weathered rock such as are found in the Black River Valley near Chester, also give an indication of the direction of ice movement.

Ice and the rock material it is carrying move toward the edge of the sheet and the terminal moraine. Movement is not uniform and, although partially controlled by topography in the lower part of the ice mass, it is, for

the glacier as a whole, independent of topography. Evidence from Greenland, Montana, and elsewhere indicate that the forward edge of an ice sheet has a relatively steep slope rising at a rate of more than thirty feet per mile. Such a slope would indicate that the ice was between twenty-five and thirty-five hundred feet thick at the New York–New Jersey border during the Wisconsin maximum when about seventeen hundred square miles of ice covered northern New Jersey. This slope and thickness would bring all of the highest points in New Jersey under a considerable thickness of ice. Erratic boulders, such as the 2000 ton, 50 by 25 by 15-foot limestone boulder on Jenny Jump Mountain, four miles south of and 300 feet above the nearest limestone bedrock, and glacial scratching on the highest ridges prove the assumption correct.

As the ice sheet "retreats" the ice itself does not move backward but rather either moves forward or stagnates and does not move at all. The "retreat" of the ice is caused by an increase in the rate of melting so that more ice melts away than is moved southward into the area of the terminal moraine by the ice sheet. The rate of melting will depend not only on the season but also on the short-range weather conditions and perhaps even the time of day. The volume of water developed by the melting of the ice may vary daily or even hourly between no water and great floods. The nature and kind of glacial deposits left by the "retreating" ice depends on the ice movement or lack of it and on the amount of meltwater flow leaving the ice sheet.

At the ice front the till, a heterogeneous mixture of materials carried and deposited by ice, is constantly rearranged and sorted by the meltwater into deposits called outwash. Later the outwash may be "bulldozed" into the moraine by the re-advance of the ice. The terminal moraine, therefore, contains both sorted and unsorted material. Its surface is irregular and usually contains numerous kettles, depressions left in the bank by the melting away of ice blocks, and kames, hills of outwash

dumped by meltwater streams or moraine material pushed up by a renewed ice advance. This type of topography with numerous small knobs and depressions was called "short hills" by the early colonists, a name which has endured in at least one area of "kettle and kame topography" on the terminal moraine. The term "drift" may be used when speaking of till, outwash, and kame deposits without differentiating between them.

The terminal moraine in New Jersey averages about a mile in width with a range of from one-half to two miles. The moraine itself may be only a few tens of feet thick or, as is the case near Dover, may exceed three hundred feet. The moraine crosses topography like a giant, poorly-woven rope of sand and gravel, from near sea level at Perth Amboy to 1200 feet above sea level near Lake Hopatcong and down to 225 feet on the Delaware River at Belvidere.

A characteristic of any glaciated area is the disorganized stream drainage. In New Jersey the line of the terminal moraine is breached by the Hudson, including the Arthur Kill, and the Delaware. In between these two rivers, however, drainage is in general to the north or east and rather disorganized behind the moraine. South of the moraine normal stream drainage follows the grain of the topography and is generally to the south or west. The Pequest, around Vienna, Allamuchy, and Great Meadows, drains the area of a former glacial lake from behind the moraine to the west. The Musconetcong does the same for a small area around Lake Hopatcong. The Watchungs, on the other hand, have formed a barrier to drainage for an area south of the moraine so that the Passaic drains the Great Swamp through the moraine to the north and east.

All of the 60 natural lakes in New Jersey are found in the area northward of the terminal moraine. Budd Lake was formed by the terminal moraine damming the upper end of a northward draining valley. Our two largest lakes, Hopatcong and Greenwood (together nearly half of New Jersey's lake area) are a combination of rock

basins excavated by the ice and the blocking of preglacial drainage by glacial deposits. Most lakes are fifty feet or less in greatest depth but a few have depths of over one hundred feet. Cedar Lake, a moraine lake in a valley at elevation 384, is the lowest glacial lake. Lake Marcia, in part a rock basin lake on the top of Kittatinny Mountain near High Point at elevation 1574, is the highest lake in New Jersey. The greatest of the New Jersey lakes, Glacial Lake Passaic and Glacial Lake Hackensack, disappeared a bit more than ten thousand years ago.

At some time before the beginning of Pleistocene time, the Hudson apparently flowed westward through the Palisades at Sparkill. It continued westward through the two Watchung ridges at Paterson. Turning southward it again passed through the gap in the Watchung ridges in the vicinity of what is now Summit. It may have flowed past Perth Amboy, or passing Newark, again recrossed the Palisades ridge in a ravine which cuts the ridge on the Bayonne–Jersey City line. Stream piracy by the Passaic, the Hackensack, and the North River (the lower Hudson on the west side of Manhattan) altered this drainage so that each of the above-mentioned gaps was probably occupied in early Pleistocene time by an eastward or southward flowing stream.

As each Pleistocene ice sheet pushed southward across New Jersey, the changes in drainage induced by the ice must have been much the same as that caused by the later Wisconsin ice the record of which is so recent and clear. As the Wisconsin ice pushed slowly southward across New Jersey, it finally blocked the exit of the Passaic River through the Paterson gaps in the Watchungs. A lake then formed in front of the ice until its waters overflowed into the darinage basin of the river which was flowing eastward through the Summit gap. This first lake decreased in size and disappeared as the ice pushed southward. The process was again repeated as the Summit gap was blocked by ice and drift. The second lake filled until it could overflow through some low point in the Watchung rampart south of the ice front. This low

point is at elevation 331 at Moggy Hollow, a mile or so southeast of Far Hills. The tiny stream, now called Moggy Brook, a tributary of the north branch of the Raritan River, thus became a major stream draining the ice front, from Summit on the east as far north and west as Dover, where drainage was to the north branch of the Raritan.

At the greatest Wisconsin advance, Glacial Lake Passaic, some eleven miles long by about eight miles wide, was less than half of its future size. Nearly two hundred feet deep over what is now the Great Swamp, the lake endured for thousands of years, a time long enough to deposit some eighty feet of glacial clay on its bottom, to develop wave-cut cliffs on the rocky island of Long Hill in back of the Veterans Hospital at Lyons, and to acquire extensive deltas of sand and gravel at Morris Plain and Towaco where swiftly flowing mountain streams, the Whippany and either a transient course of the Rockaway or perhaps the Pequannock, entered the quiet waters of the glacial lake.

While the Ice front stood in the area of the terminal moraine, the till deposited by the melting ice accumulated until islands of gravel and sand, in addition to the rock islands to the south, projected above the waters of the lake. Wave action modified the accumulation of till and outwash to form the flat-topped terraces and gently rolling ridges between Morristown, Madison, and Chatham. The continuous forward movement and melting of the ice sheet in the Chatham, Summit, Short Hills–Millburn area caused such an accumulation of till and outwash (terminal and ground moraine) that the former water gap was effectively sealed against drainage from north or west of the Watchungs. Thus as the Ice front withdrew, because of the increased rate of melting, the waters of Glacial Lake Passaic would have increased in area and remained in contact with the ice front.

When the Ice front had melted back to the latitude of Great Notch, the lake level probably dropped to about 303 feet, the level of a new outlet. The overflow through

Moggy Hollow then ceased. As the Ice front retreated farther uncovering the Paterson gap, the lake was drained and the present Passaic drainage developed. The Great Swamp and the several nearby meadows are the clay-filled remnants of the lake bottom of Glacial Lake Passaic.

Shore line features developed by Glacial Lake Passaic extend north of Mountain View along the sides of Hook Mountain indicating that, for a time at least, the waters of the lake could not overflow an ice block in the Paterson gap. The shores of this 30-mile-long, 10-mile-wide, greatest of all New Jersey lakes, are indicated on the latest State Geologic Map (1950) by a special dotted line.

It is reasonable to believe, and some evidence of lower shore lines and till overlying lake clay suggests, that pre-Wisconsin glacial lakes were formed in the Passaic Valley. The Summit-Millburn gap may have been open or only partially blocked by earlier ice sheets so that the lakes formed may not have been so deep or so extensive as that developed by the Wisconsin ice. On the other hand, Illinoian and Kansan ice sheets may have formed and then overwhelmed similar lakes as they advanced. These ice sheets may have covered the entire area of the Passaic Valley and the western Watchungs including the Moggy Hollow outlet.

Glacial Lake Hackensack was formed during the waning of the Wisconsin ice in the area north of Staten Island, west of the Palisades, and east of the Watchungs. The shore lines of this lake are less obvious and the overflow points in the moraine to the south have long since been eroded away. A water gap through the Palisades, however, very similar in size and cross section to today's Ausable Chasm in northern New York, is found filled with glacial deposits at the Bayonne–Jersey City line. The preglacial stream valleys behind this gap are filled with varved lake clays which in some places are nearly two hundred feet thick. Wells and test borings suggest that there were perhaps two periods of deposition of lake

clays separated by an interval of erosion which deposited sand and gravel on the earlier clay. The story of Glacial Lake Hackensack is further complicated by the flooding of the area, because the bottom of the former lake is at today's sea level.

When the Wisconsin ice was upon New Jersey and Glacial Lake Passaic was overflowing through Moggy Hollow, the Raritan apparently flowed south through the Rocky Hill gap and either up the present Millstone and across the Coastal Plain or southwestward past Princeton to Trenton where it joined the Delaware. Sea level was much lower than it is now and the Jersey shore was on the continental shelf many miles east of our present beaches. Seaward of Sandy Hook the configuration of the ocean bottom shows a great delta of the Hudson River beyond which is the Hudson Canyon. The canyon is probably of Pleistocene age and its origin is a fascinating tale, but not of New Jersey. At Penns Grove an ancient valley of the Delaware, over eighty feet deep and parallel to and a mile or so south of the modern estuary, is cut in the Cretaceous Raritan formation. This valley is now filled with Pleistocene sands and gravels. In a similar manner the valleys of the Millstone River, south of Princeton, and of Assunpink Creek east of Trenton have been filled with one hundred feet or more of Pleistocene sands and gravel.

These fillings of modern, and not so modern, river valleys by sediments deposited by the floods of meltwaters from the continental glaciers clearly indicate two things: the volume of water in many of our present rivers is a mere trickle compared to the floods that occupied the valleys when the ice caps were melting, and deposition of sediments occurred in the flooded interglacial estuaries just as it does in the Delaware below Trenton today.

The characteristic topographic features found behind the terminal moraine are quite different from those found in front of the ice sheet beyond the moraine. Behind the moraine both ice and meltwater leave various special types of sedimentary deposits. Examples of most

of these are found in northern New Jersey. A streamlined hill or drumlin-like deposit of till plastered against some obstruction by the passing ice is found just south of East Orange. Eskers, the long serpentine ridges of sand and gravel laid down by streams or meltwater flowing in tunnels beneath or in the lower part of the ice, are found at a number of places but are most abundant in Bergen County. Several eskers are found around Wyckoff and Mahwah; others are found in the vicinity of Ramsey, Rochelle Park, Allendale, Hillsdale, Union, and West Livingston.

Ground moraine, the irregular and usually thin cover of till left in place after the ice has melted away is found almost everywhere. Most obvious on the sides of ridges, it is found beneath outwash and kame deposits in valleys, and may have been washed off the ridge tops where bare rock outcroppings are now more abundant. At several places, such as near Culvers Lake, Warbasse, Wyckoff, and Old Tappan, thick accumulations of drift indicate pauses in the "retreat" of the ice. At these locations melting, for a number of years, did not exceed the rate of forward movement of new ice; the ice front seemingly remained stationary while a recessional moraine piled up. Ground moraine, recessional moraines, and even the lateral moraines formed in the Kittatinny Valley by the Tazewell ice tongue, are all at times buried or modified by the occurrence of kame deposits in the same area.

As indicated earlier, kames are hills or ridges of both sorted and unsorted material dumped in or against the ice by the meltwaters which are carrying off the sediments that were trapped in the ice mass. One of the most spectacular deposits of this nature is found at Ogdensburg where a crescent-shaped embankment is found across the valley of the Wallkill. Nearly a thousand feet wide at its narrowest point, it is almost four miles wide on the east side of the valley. The natural embankment rises about a hundred feet above the floor of the valley. The material was apparently deposited in a huge crevasse which developed in a tongue of stagnant ice which filled

the valley. The material is stratified, indicating deposition by water, but has a wide range of sizes and large boulders are found at random in the mass.

A more common variety of kame is that found along the edges of the northern New Jersey valleys. Reflection of the suns rays from the bare rock ridges and ground moraine along the sides of a valley on to the ice still occupying the valley causes the ice adjacent to the valley wall to melt more rapidly. In the space thus formed between the side of the valley and the tongue of ice long narrow lakes of meltwater accumulate. Sediment laden streams from the top of the ice and from the bordering rock ridges deposit clay, sand, and gravel features called kame terraces in these transient lakes. Each lake persists until the waning of the ice opens a new lower outlet for the meltwater streams. Thus kame terraces may occur at any elevation but are most common at the lower elevations along the valley sides. The outlets of these ice border lakes may be marked by boulder-paved passes in the ridges beyond which, usually to the south or east, are extensive outwash plains such as those found to the north of Stockholm or south of Lake Wawayanda.

Kames, outwash, and ground moraine may so fill an old stream channel that the river is forced to cut a new course, at times a gorge in solid rock, in its efforts to drain the watershed. The sharp bend in the Delaware immediately upstream from Belvidere, the course of the Rockaway at Boonton, or the course of the Wanaque east of Haskell, are examples of the diversion of a river from a section of its preglacial channel by glacial deposits which blocked the old valley.

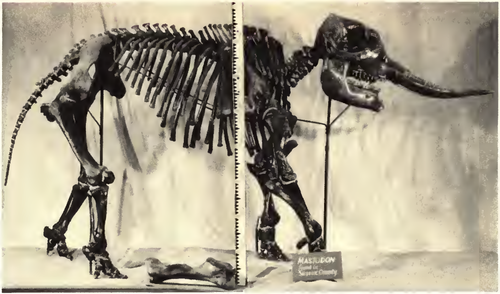
The numerous swamps in glaciated areas are another example of the disorganization of the drainage. Some swamps are found above the clays of old lake bottoms, while others are the vanishing or vanished lakes left behind moraine dams, in kettle holes, or by kame terrace deposits. The filling in of a lake or pond first by weeds, then by bushes, and then trees can take place in one or two generations. The process is, and will be, the natural

and eventual end of all of our northern New Jersey glacial lakes. It is quite possible that the "old swimming hole" really isn't as big or as deep as it used to be. The dragline and bulldozers have been used to make recreational lakes and thus reverse the natural sequence of events. In the making of Ohberg's Pond near Vernon, a very complete and well preserved skeleton of a young female mastodon was recovered ("Matilda" is on display at the New Jersey State Museum).

The unsorted till of the glacial moraines is neither a good source of well water nor suitable for most sand and gravel operations. The high percentage of silt and clay inhibit the flow of ground water and for the sand pit require washing before the sand and gravel can be used in most construction. On the other hand, kames, terraces, outwash, and eskers, deposited and sorted by moving water, have a high porosity and permeability so that good wells with high yields are not unusual and sand pits can work material that has already been washed and sorted.

Many Pleistocene swamps are worked as truck farms (Great Meadows, the black earth belt near Paramus, and numerous other smaller areas that were once glacial lakes). Around Newton, the numerous peat bogs are the source of the New Jersey peat moss industry.

In front of the terminal moraine the land is still covered by outwash deposits and by the "regolith," or zone of weathered and broken rock derived from the immediately underlying bedrock. Drainage is not disorganized, and except for the "valley trains," moraine plains, or outwash deposits, there are no glacially derived materials, unless there be erosional remnants of earlier glacial stages. Near Chester in the Black River Valley and at one or two other places, this thick (40 to 80 feet) regolith of the pre-Pleistocene crystalline rocks, because of the direction of the valley or adjacent ridges, has been preserved from removal by the ice of the "older drift" of Illinoian and Kansan glaciation. Elsewhere in the Highlands, the areas covered by earlier glaciation but now



A MASTODON FROM SUSSEX COUNTY

"Matilda" the Ohberg Sussex County mastodon, found February 19, 1954, south of Vernon, Sussex County beneath nearly twelve feet of peat in a bog on top of Wawayanda Mountain at 1240 feet above sea level. A young female, nearly seven and one half feet high, Matilda died about 10,000 years ago. Note her conical pointed teeth which distinguish a mastodon from a mammoth and from the modern elephant.

New Jersey State Museum

south of the Wisconsin moraine have been weathered and eroded long enough to establish again a soil profile and a regolith. Thus the Highlands south of the Wisconsin terminal moraine are characteristically gently rolling, soil-covered slopes devoted to farming, while to the north of the moraine most of the Highlands are rocky ridges covered by forests.

Near Plainfield the west side, or front of, the Wisconsin terminal moraine is a very flat gently sloping "outwash or moraine plain" deposited and formed by water from the melting ice cap as it ran off into the drainage of the Raritan near Bound Brook. A similar feature known as the Succasunna Plain is formed in front of the moraine southwest of Kenvil.

In the trenchlike valley of the Delaware there are abundant flat terraces of gravel from 10 to 20 feet or more above the level of the river. Sometimes on the New Jersey side, as between Frenchtown and Lambertville, at other times on the Pennsylvania side, as between New Hope and Morrisville, the terraces represent the deposits from the greatly enlarged flow of the Pleistocene Delaware. Such deposits of sand and gravel in a river valley leading away from the forward edge of a glacier are known as "valley train deposits." Occasionally, as this train of debris was deposited by the meltwater floods, large boulders were dropped from the ice cakes or ice pans as they floated down the river. Because of the larger drainage area and the greater length of time that the ice occupied the Delaware drainage basin, its "valley train" is the best developed and longest in New Jersey. However, to a lesser extent, Flat Brook, the Pequest, the Musconetcong, and the Raritan each has a valley train. For some of the streams the valley train is concealed or modified by kame deposits or underlain or bordered by remnants of the "older drift," or even by a valley train deposit from an older glaciation. In the Raritan Valley, south and west of Bound Brook terrace deposits (the river drift of the 1950 Geologic Map) which may represent an early valley train are found but are not yet precisely fitted into the sequence of Pleistocene events.

Only west central New Jersey in the area of the Hunterdon Plateau, the Sourland Mountains and the adjacent lowlands west of the South Branch of the Raritan and north of a line from West Trenton to Princeton is free of surficial deposits related to Pleistocene glaciation. This statement, however, is slightly incorrect as a considerable portion of the area, particularly the southern part, is covered with Pleistocene wind-blown silts or loess. Between the Wisconsin terminal moraine and a line from Metuchen to Kingston to Lawrenceville and West Trenton, except for the area mentioned above, there are scattered outcrops of old drift, or river drift, and of Pennsauken gravels. Within the lower elevations of the drainage basins and in the trenches of the present river valleys, we thus find, between elevation 200 and present sea level, deposits which are of undoubted glacial origin and other materials which are almost certainly from an interglacial age.

South of the Metuchen–West Trenton line, parts of the surface of New Jersey are covered by yellow sand and gravel formations that are predominantly of interglacial age. The yellow gravels may be in part the valley trains from the ice sheets, are certainly in a larger part stream deposits graded to higher interglacial sea levels, and in part marine deposits along the coast or in the flooded estuaries of interglacial times. Fossils in the yellow gravel formations, other than those in the Paleozoic pebbles, are extremely rare. A few plant remains found in the Pennsauken formation suggest a climate warmer than now as does a marine invertebrate fauna in clays in the Cape May formation. Other evidence along the northern border of the yellow gravel formations and occasional ice rafted boulders suggest that the yellow gravel formations were deposited at least in part during glacial times.

In many areas of central New Jersey it is difficult, if not impossible, to distinguish one yellow gravel formation from another. The degree of weathering, the type of contained pebbles, and the topographic position (elevation) have all been used as criteria for distinguishing one

formation from another. The mapping of the formation and the correlation with interglacial or glacial ages has been based to a large extent on assumptions which are no longer consistent with our knowledge of Pleistocene events and not always confirmed by field evidence. It would seem advisable, therefore, since the formational subdivisions are not always clear and do not wholly fit the sequence of Pleistocene events, to class the whole group, including the Pliocene(?) Beacon Hill gravels, merely as "Pleistocene yellow gravels." Where the sediments are at a higher elevation (150 to 200 feet) or are on a slightly eroded underlying formation, they were probably deposited in interglacial times, if they are not remnants of the "older drift." Where the sediments fill valleys, now close to or below sea level, they may either be valley trains adjusted to the lower sea level of glacial times or the deposits of rivers in flooded estuaries during the waning of the glacial age. As now used in the Pleistocene literature, each of the yellow gravel formations was deposited during an interglacial and part of a glacial age.

At present the Cohansey formation, the topmost of the Coastal Plain sedimentary formations, is considered to be late Miocene or perhaps Pliocene age. A few occurrences of gravels are found on the tops of the highest hills in Monmouth and northern Burlington and Ocean counties. Once classified as part of the Cohansey, they are now considered to be the Beacon Hill formation of Pliocene age. It is quite possible that both formations are Pleistocene.

There are four "yellow gravel" formations. As originally classified, a younger formation should be lower topographically, less weathered, and nearer the present coastline than the next older formation. The highest, oldest, most weathered, and most centrally located formation is the Pliocene (?) Beacon Hill gravel. The Bridgeton formation found on higher elevations in the central coastal plain is lower and less weathered than the Beacon Hill. The rather widespread Pennsauken formation is

next youngest in age followed by the low-level coast rimming Cape May formation.

As originally proposed, the subdividing of the Pleistocene formations was based on three instead of four glacial ages and only one Wisconsin ice advance. Each formation was deposited at a lower level because of the erosion of the earlier formations which took place during the glacial age when sea level was low. Each interglacial age, a time of higher sea level, is considered a time of deposition but the sea level and the material deposited are in each instance assumed not to have reached quite as high a level as the sea level during the preceding interglacial age.

In spite of such a basis of classification, the facts are that: younger gravels are found at a higher elevation, particularly toward the headwaters of the present drainage, than the older gravels along the coast; the formations are so similar in lithology that identification is difficult and at times impossible; the lithologic difference is to a large extent dependent on the degree of weathering; depth of weathering does not conform to the stratigraphic position of the deposit.

The Bridgeton is classed as equivalent to the Aftonian or first interglacial and also to the Kansan or second glacial age. No equivalent of the earlier Nebraskan or first glacial age, such as the Mannette Gravel of Long Island, has yet been identified in New Jersey. Thus a very deeply weathered glacial deposit is roughly equated to a not so deeply weathered outwash or interglacial deposit. Also a high-level weathered gravel for some reason is considered to be Pliocene in age or older than the oldest and most deeply weathered glacial drift.

The Pennsauken, which covers the greatest area and is the thickest of the Cenozoic formations, except for the Cohansey, is considered equivalent to both the Yarmouth or second interglacial and the Illinoian or third glacial age. The Cape May formation, youngest in the series, found rimming the coast of New Jersey below elevation 50, is assigned to the Sangamon or fourth interglacial age.

The valley train of the Delaware River and minor outwash deposits elsewhere, such as the Trenton Gravels, are the only outwash deposits assigned to the Wisconsin or fourth glacial age found in the state.

The present Pleistocene stratigraphy of New Jersey thus contains several unanswered questions. The correlations of outwash and marine deposits in southern New Jersey with whole sequences of glacial deposits in the northern part of the state is either awkward or has not been attempted. The most intriguing question, which is yet to be worked out is: what would the correlation look like if the Cohansey were the outwash deposits of the earliest Pleistocene (Nebraskan) glaciation which removed the thickest of all regoliths in northern New Jersey?

From quite a different point of view the present Pleistocene stratigraphy may also be questioned. The fertility of each of the yellow gravel formations, because of the greater degree of weathering of the older formation, should be different. However, this does not always hold true if the existing map is used. Supposedly different gravels may have the same fertility suggesting that they have suffered the same degree of weathering. Also glossed over in the Pleistocene stratigraphy are the elevation and correlation of the not too uncommon buried cedar forests found around the New Jersey coast which have not been petrified and the occurrence at higher levels of petrified cedar logs between the Pleistocene yellow gravels and the older Coastal Plain formations.

The Pleistocene formations, whatever their age within the period, filled the valleys which had been cut across the Coastal Plain sediments during times of lower sea level. In the vicinity of Trenton, the Pennsauken, and perhaps, locally, some underlying Bridgeton, filled valleys cut more than a hundred feet deep in the Cretaceous Coastal Plain sediments. Since the present surface is about a hundred feet above sea level, the pre-Pennsauken valley must have been eroded until adjusted to a lower sea level than today's. Erosion since the deposition of

the Pennsauken has, however, been sufficient to remove the Coastal Plain sediments from those areas not protected by this Pleistocene fill. The gravels deposited in the former valleys are now found capping the present ridges. This relationship of Pleistocene deposits to the earlier Tertiary and Cretaceous sediments indicates that post-Wisconsin erosion has been sufficient to cause an inversion of topography in the Coastal Plain since the deposition of the Pennsauken.

Although we cannot say with precision which "Pleistocene yellow sands and gravels" were deposited when the sea was up and which when it was down, we can be sure from evidence outside New Jersey, that the sea was higher than now, perhaps as much as two hundred feet, during the interglacial stages and lower than now, perhaps three hundred feet, during the glacial ages. Such changes in sea level would have a profound effect upon the area of Coastal Plain New Jersey. Much of the subdivision of Pleistocene formations is based on terrace levels and in a few instances poorly developed shore-line benches or cliffs found at elevations up to about 200 feet for the Bridgeton, 130 feet for the Pennsauken, and 30 to 50 feet for the Cape May formation.

Perhaps the least understood of the Pleistocene effects is the climate of the area in front of the ice. Alternate melting and freezing not only caused extreme fluctuation in the amount of water and, therefore, the amount of sediments in streams flowing from the ice front but also caused frost heaving and ice cracking of the sediments and regolith. The development of ice polygons, of frost-heaved ground, and of accelerated weathering has been studied in the tundra areas of the far north. As the New Jersey Pleistocene deposits and soils are restudied evidence of ice cracks, of ice polygons, and other phenomena of an arctic climate and tundra conditions have been observed in newly exposed sand banks.

The terrain of such a cold desert is a favorable locale for wind erosion. When the streams are dry during the cold spells, winds can and do pick up loess (wind-blown silt) and even sand. Loess deposits are most common

close to and east of the Delaware River. On the west side of the Hunterdon Plateau, loess has collected in many depressions on the steep slopes bordering the entrenched Delaware River. Farther south from Washington Crossing and Titusville where the river trench is not so deep, loess is more widespread and occasionally several feet thick over the lower or flatter slopes of Hopewell, Princeton, and Ewing townships. In the vicinity of Runnemede, a nearly continuous layer of gravel, a single pebble thick in some of the Pleistocene cut banks, suggests a period of wind erosion which left a "desert pavement" or only the fragments too big to be blown away.

Frost-heaving phenomena in the shales, soft sandstones, and in the Coastal Plain sediments have not always survived the post-Wisconsin erosion. The evidence is frequently turned up in deeper excavations from Cape May to Clinton and east to the terminal moraine near Metuchen. Some shales near Clinton, for example, have been so weakened by frost action that they are not acceptable by the Highway Department for fill because they break down within a year or so into a mass of clay which causes the collapse of the fill by landslide and slumping.

The dating of the various Pleistocene events, which until recently relied upon changes in sea level, degree of weathering, and stratigraphic relationships that were often obscure, has now been greatly improved by the use of the radioactive carbon dating methods. Radiocarbon methods depend on the finding of organic material, such as wood and invertebrate or even vertebrate remains, in the Pleistocene deposits. As indicated earlier, such occurrences are rare in New Jersey. Another new dating method uses the relative development of soil profiles and the leaching depth for lime from the gravels of kame terrace, marine, or outwash deposits. Even with valuable new tools for deciphering the record of prehistoric New Jersey, reliance must be placed on observation, logic, and hypothesis, since primitive man did not record the geologic conditions.

In addition to the inversion of topography, the de-

velopment of late Wisconsin soils, to a degree, controlled the land use in present-day New Jersey. The previously mentioned loess soils in Mercer and Hunterdon provided rich farm areas in Colonial times. The frost heaving of the Triassic and Coastal Plain areas provided more favorable conditions for rapid soil formation.

Some areas of the State, however, were not so favorably affected. The sand dunes and beaches of a high interglacial sea level left porous permeable sandy soils in the Lakewood area. Consisting almost entirely of quartz, an inert and almost insoluble mineral, it is so well drained it has been nearly impossible for a soil to develop on the underlying parent material. The Croten soils of the Hunterdon Plateau, on the other hand, have been weathering in place since the early Tertiary. Unglaciated, uneroded, on a flat terrain, the soil has been leached of nearly all of its nutrients and become a heavy clay difficult to drain. It is called by some soil scientists an "indefinable agglomeration of undesirable constituents," by others, a senile soil no longer responding to climate, slope, or parent material, the three great determinants of the type of soil which will develop anywhere in the world.

The economic demands for multiple high-value crops from the gardens of the Garden State have led some farmers to work—very successfully too—the peat bogs or black earth meadows of northern New Jersey rather than try to improve some other soil by applying imported peat. By this change in use, production of New Jersey's only mineral fuel commodity, peat, in less than a decade has dropped from fourth or fifth in the national total to near the bottom of the annual tonnage figures, yet another case of an ore that is still there but no longer mined.

In southern New Jersey the demand for fertile soils adjacent to a means of economical transportation to market, in this case boats, led to the reclamation of many salt marshes by "banking" and draining. Indeed several such "bank meadows" along the lower Delaware in

Salem and Cumberland counties are still being maintained by the same methods which have been used by the Dutch for years. It is almost ironic that the success of these operations in southern New Jersey did not lead to the reclamation of the Hackensack Meadows long ago. Actually, in pre-Colonial times the Hackensack Meadows were apparently fresh-water swamps supporting a cedar forest indicating, as do other more deeply buried forests, a lower sea level than the present.

From the discussion of glacial and interglacial sea levels, we can surmise that sea level during the Pleistocene has gone up and down like a yo-yo. As a result of these many changes, the present New Jersey shore is classed as a compound shore line. The Cape May terraces at about thirty feet indicate an emergent condition; the flooded estuaries of the Delaware, Mullica, Hudson, and other rivers, a submergence; and the offshore bars that form our famous beaches indicate an emergence. This apparent inconsistency of change in sea level results from the combination of a rising sea level, as the ice sheet melts and returns water to the sea, and a steady, but lagging, elevation of the land as it slowly responds to the effect of removal of the weight of the ice cap. Since New Jersey is near the forward edge of the ice, the depression of the coast has been slight and the rebound slow. Thus at the moment emergence has a slight dominance, even though in the closest prehistory the sea was ahead in the race, causing a more obvious submergent condition.

When the flat wave-planed ocean bottom is raised even slightly, wave action begins to erode the bottom sediments and pile the material in the breaker zone. This pile of material, as it approaches the level of average tide, becomes a bar. Wind begins to assist the waves by piling up dry material to form dunes behind the beach as soon as the bar is high enough to dry out for even a few hours. Wind cannot move wet material as well as it can shift dry sand which lacks the binder of a film of water around each grain.

STORM DAMAGE AT THE SHORE

Storm damage in March, 1962, between Ocean City and Sea Isle City. Note the stubs of piling from a boardwalk destroyed about twenty years before in an earlier storm.

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The water in the lagoon behind this barrier maintains channels (inlets) through the bar in order to empty and fill with the changing tides. Since the flow in and out is not in phase with the changes in tide level, the volume and velocity of water in these channels varies from time to time and place to place. Shoals develop and disappear to meet the changing ability of the inlet (and outlet) currents to carry their loads of sediment. The impact of the waves along the coast at an angle to the beach develops what is called the "littoral drift," or the movement of sand in a direction parallel to the beach. This movement of beach material tends to close, shift, or modify the inlets, wash away some beaches, and build up others with points and hooks. Much of man's puny efforts are devoted to building protective works to maintain inlets or preserve beaches.

The complexities of shore-line erosion on a sandy coast have been studied in many areas for many years but are still understood in only a most general way. There are only rare instances when other geologic agents of erosion can equal the force and magnitude of the shore erosion processes during severe storms. In 1944, in four hours during a hurricane, and again in 1962 in two days of a northeast storm, a total of eight miles of New Jersey beach and dune at three locations, Harvey Cedars, Holgate, and Ludlam Beach, were completely washed away and swept clean and flat from the breaker zone to the bay or salt marsh some miles inland. Extensive damage was caused elsewhere along the Jersey shore. At such times tides eight to ten feet above normal cause havoc in the low-lying areas of the mainland shore and on the bay side of the offshore bar.

The spectacular changes in the coast after each storm may be remembered for a while but seem, as compared to the whole beach area, to be insignificant and isolated bits of damage. In the long scope of geologic time, however, six inches here and ten feet there add up to a net retreat of most of New Jersey's beaches to the west, toward the mainland, at a rate averaging almost two

DAMAGE AT THE SHORE, 1962

Looking south from the Beach Haven Inlet Coast Guard Tower after the March, 1962, storm. The U.S. Navy Destroyer *Monssen* is aground behind the line of the main highway on Long Beach Island, which prior to the storm was behind the dune line. In 1936, the point was less than three-fourths of a mile from the jetty. The southern end of Long Beach Island is now approximately one and a half miles south of the jetty. In 1915, the point was approximately three miles farther south.

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THE SHORE AFTER 1962 STORM

View to the northwest from the Coast Guard Tower at Beach Haven Inlet showing the comparatively slight damage to the buildings and house trailers protected by a line of high wide sand dunes and one or two jetties. About two miles of the beach to the north and the beach to the south (see preceeding picture) were completely leveled by wave action at the height of the storm.

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feet per year. From Highlands to Bay Head the barrier beach has reached the present mainland shore. From Bay Head to Ocean City, the bar is still far enough out to permit the lagoon (Barnegat and Great Bay) to remain open to the ebb and flow of considerable water with each tide. From Ocean City to Cape May the bar is close enough to the shore so that, like the glacial lakes, vegetation is filling in the shallows and inevitably destroying the lagoons and reducing the volume of water moving in and out of the inlets and "thorofares."

The compressed marsh muck, revealed on the beach at low tide after a storm, is not evidence of a sinking coast but rather a barrier beach migrating shoreward as the waves adjust the offshore bottom to the new, slightly emergent sea level. The rise in sea level, which is occurring, is a matter of inches per century while changes in the level of the New Jersey mainland are not measurable.

The changes in the coastal frontier of New Jersey, whether it be the accumulation of talus at the foot of the Palisades along the Hudson, silt in New York Harbor, the Kills, or Raritan Bay, the building up of Sandy Hook, the retreat westward of the Jersey shore, the extension of marshes in the Delaware Bay, or the filling in of the channel of the Delaware are all the result of the interaction of the forces of tide, wind, wave, gravity, and moving water under changing weather conditions. What happens at any location is influenced by the inhabitants of the biosphere whether they be salt hay, bayberry on the dunes, clams and other bottom-dwelling life, or man and his "protective works." The whole system is one of extremely complex variables in space, direction, weight, force, and time. The changes in the seashore, due to storm wave and wind, are a whole story in themselves. Coastline changes are inevitable and fit a general pattern, if we wish to discern it. That there will be change, with each tide and storm, is certain as the centuries bring us out of the latest glacial age of the Pleistocene.

IX

GEOGRAPHY AND MAN

LAND FORMS, THEIR ORIGIN, classification and significance in the development of the landscape and of the resources required by man fall within the purview of both geology and geography. Whereas geology considers the materials beneath the surface and their origins over the eons of geologic time, geography is concerned with the surface of the earth, its climate, its flora, its fauna, and its resources of soil, water, and ores as they are used by man in his activities. If geology is material, time, and process, geography is man, land, and climate.

Of all the creatures which have lived on the earth since Precambrian times, only man has not and will not accept nature as it is. Reptiles and later mammals have, in the course of their evolution, developed swimming, flying, and specialized land forms to conquer the air, the water, and the changing surficial conditions. As Georg Zappler has pointed out, man is a new type of creature who will not adapt to his environment, but rather uses his wisdom to change the conditions under which he lives. The primates sometimes walk erect, gather in groups, signal by grunts or howls, and on occasions may use stones or tree limbs as weapons. Man entered the scene when a primate ancestor thought about and began to chip stones, sharpen stakes, and otherwise process natural materials for use as tools, shelter, or weapons. Man's deliberate, planned, conscious efforts to change and improve his environment sets him apart from

all other creatures. Instead of fins, fur, or feathers, man has boats, clothes, and flying machines.

The artifacts that have been unearthed some twelve feet or more below the present surface of gravel terraces along the upper Delaware indicate that the first men to inhabit New Jersey arrived late in the Pleistocene, about 6000 years ago. The mastodon and other now extinct Pleistocene animals were probably hunted by these first Indians. The earliest Jerseymen knew the use of fire, had a language, and had developed an intelligent, but nonliterate society. Elsewhere in the world man had reached an even higher cultural level, in which he lived in communities, raised crops, and domesticated animals. The use of metals, a knowledge of mathematics, and written records followed in a few thousand years. Significant advances in these areas did not occur in New Jersey until the arrival of the European immigrants thousands of years later.

In the development of any region, the geographic factors have different relative values as the knowledge and activities of man change through time. In the development of any territory, the first society is based on hunting and fishing. Then usually a search for mineral resources opens up the routes of trade necessary for an agricultural society. With the ability to provide food for a larger population, the way is cleared for community living with its crafts and industrial activities.

In the Indian and Colonial society of New Jersey there was little that could be done about the effects of soil, weather, or climate. Today's detailed knowledge of soil was to come, but certain areas were recognized as desirable for settlement in that they were more easily cleared and tilled. There was a general appreciation of natural conditions which has been lost by many of today's planners, developers, and home owners. Have you ever seen a colonial mansion built on the flood plain of a major river or on the dunes at the seashore?

In New Jersey, man realized early that salt marshes and soils predominantly of one material would not pro-

vide the water, drainage, flora, or fauna required by hunting or agricultural communities. The extremely rugged topography and the rocky soils or bare rock outcroppings of the Watchungs, of Kittatinny Ridge, and of the glaciated parts of the Highlands, and the flats of the salt mashes and sandy south Jersey barrens appealed to neither Indian nor European for settlement.

The geography of a region can be described in many ways. Some discussions are mere classifications of facts. An earlier school of geographers believed that land use and man's activities are determined by the factors constituting the physical environment. Now it is realized that topography, geology, soil, weather, climate, agriculture, industry, land use, political organization, economic conditions, and social beliefs, all influence where and how man lives. Each factor may at one time or another be dominant in shaping the local picture, and each may be an important or even controlling influence in the long-term view. It is essential to recognize that the importance of the physical environment as a geographic factor is constantly changing as man evolves and changes his social beliefs, his activities, and his desires. Factors such as geology, topography, and climate are comparatively stable in the overall picture but can be significantly changed in small areas as man makes use of his knowledge of natural conditions. Man's knowledge is the keystone of geography. Within such a frame of reference, the geographic evolution of New Jersey can be divided into four periods: the Indian period before 1600; Colonial, 1600-1830; Industrial, 1830-1930; and Modern, since 1930.

During the early part of the period of Indian occupancy, the climate was probably a good bit cooler. The distinctive flora of some northern New Jersey ravines suggest that the State had a boreal climate similar to that of northern Canada today. The topography was much as it is now and the land was probably completely wooded. During the entire 6000 years of man's use of New Jersey land, there has been no significant change

in the geology or topography. Any change in climate or soil conditions has been so gradual that it has not been significant as a cause for changing land use. Man's better understanding of these factors has greatly changed their importance as they relate to human occupancy in the last few decades. The change in geography has not come about in the environment, but from man's changing his pattern of living within the limits imposed by nature. The physical limitations imposed by land conditions have become less significant in each of the periods. The relationships between man and his neighbors have changed as man has grown in knowledge and become more numerous. Salt marshes, lakes, ponds, and fresh-water swamps were nearly as abundant as they were when the first Europeans landed. Some lakes were filled, as all lakes must eventually be, by growing trees, bushes, and grasses. Some swamps and lakes may have been drained as a result of the normal progress of stream erosion. Some salt marshes grew larger as sediments accumulated in the tidal bays. Whether the early Indians saw Glacial Lake Passaic, or a pond at Great Meadows, we do not know.

The modern Indian, the Lenni Lenape or Delawares, lived in an area whose climate and topography we know because it has not changed in three centuries. Their trails extended to the sea for salt and sea food, and to the interior for hard rocks and minerals for their implements. Weapon points and other artifacts indicate that there was trade with distant tribes. The territory of New Jersey at this early date had been divided by its estimated seven thousand inhabitants into three political subdivisions or tribal areas.

Each tribe was centered on a locality which was to be settled early in colonial history. With the minimal needs and the limited agriculture of the Indian, the factors of soil, weather, and topography were not so significant as they would become in the later geographic development of the State. Each tribal center, one in the Coastal Plain, one at the edge of the Piedmont, and

one in the Ridge and Valley physiographic province, was, none the less, accessible from a large area of the adjacent countryside, had a more protected and favorable local climate, and was in a well watered and fertile part of the State.

From the voyages of discovery to the beginning of the Industrial Revolution, the geographic development of New Jersey was directed by its flanking rivers, the Hudson and the Delaware, and their tributaries. New Jersey's favorable geographical location, between two of the best harbors on the Atlantic coast, is augmented by navigable waters which form nearly three-fourths of the State's boundary. New York Harbor and the Hudson River provided easy natural access not only to the interior of North America, but also via the Wallkill to northwestern New Jersey, and via the Hackensack and Raritan to the northern part of the central Jersey Piedmont. Philadelphia, at the mouth of the Schuylkill, had natural access to the interior of Pennsylvania, the Great Valley, and the southern part of the central Jersey Piedmont.

The grain of New Jersey topography provides two low-level cross connections between these natural water routes to the interior of the continent. One is the well-known corridor across the State between Trenton and New Brunswick. The other less well known, but vitally important during the American Revolution and the period of Colonial development, was the Kittatinny Valley and the parallel valley of the upper Delaware, the Minisink of the Indians, in northwestern New Jersey.

The Highland ridges breached by the water gaps of the Hudson, the Delaware, and the Schuylkill have only three passes below the summit level in the area now called New Jersey. The ridges are, and always have been, an obstacle to overland movement in a north-south or northwest-southeast directions. Because of the restrictions thus imposed by topography, modern superhighways and earlier roads, railroads, and even canals, have utilized the same key land forms as the Indian trails.

The topographic relationships between tidal waters and an easily accessible low-level hinterlands helped shape the pattern of early settlement. The Dutch in the middle of the seventeenth century moved up the Hudson to Kingston, New York, and then constructed the mine road to Pahaquarry. This road opened up northwestern New Jersey to settlement at a much earlier date than would have been the case otherwise. The region from the Amboys to Hackensack, accessible around the Palisades barrier through the numerous bays, estuaries, and rivers, became the center of settlement for both the English and the Dutch and later for the New York metropolitan complex. The fertile and flat land adjacent to the lower Delaware was occupied by the Swedes and the English. In each instance, the most important controlling factors were accessibility from the sea, sheltered anchorages, and a low-lying flat to gently rolling terrain with fertile well-drained soil.

Just as the first areas of settlement have become the areas of today's major urban concentrations because of favorable topography, soil, and climate, so the major empty areas of the State have remained sparsely settled since earliest times. Ignored by the Indians because of unfavorable topography, soil, and to a lesser extent climate, their chief use has always been and seemingly will remain hunting grounds. Hunting, once a necessity, is now part of an increasingly important land use: recreation. In spite of this change in motivation, topography, climate, fauna and flora in the empty areas remain essentially unchanged by man.

All but one of the boundaries of New Jersey are natural features. The boundaries and the physical dimensions of New Jersey, as we know it, were finally established in 1772 with the agreement which defined the New York–New Jersey boundary as the 48-mile-long survey line from Tri-State Rock in the Delaware to the Hudson River. Arguments with neighboring states as to exactly which lands belonged to New Jersey continued well into the nineteenth century. The principal prob-

lems concerned Staten Island, which islands in the Delaware River belonged to Pennsylvania, and exactly where the boundary between Delaware and New Jersey was to be located in the Delaware River. Even today there is a disagreement between the Federal Government and New Jersey as to whether the 368 square miles of water in lower New York and Delaware bays should be included in the total area of the State. Since the State enforces its laws in these waters, it considers them as part of the 8204 square miles of land and water which comprise New Jersey. As defined by the Federal Government, New Jersey has an area of only 7836 square miles. Both figures appear in different reference sources and hence cause a good deal of confusion. Population figures and census information are based on the smaller area. Since there are few houseboats with permanent residents on lower New York Bay or Delaware Bay, the smaller area presents a truer picture of population density—state pride and legal niceties notwithstanding.

In Colonial times High Point was, as it is now, 1803 feet above sea level. The longest dimension of New Jersey, the 166 miles from Tri-State Rock in the Delaware north of High Point to Cape May, was perhaps a mile longer in the Colonial period. In 1796 the Federal Government acquired land at Cape May for the establishment of a lighthouse. This site is now a shoal 1500 yards offshore. The deed to the acreage was recently returned to the State.

The 57-mile-width from the Jersey shore of the Delaware opposite Chester to Great Egg Harbor Inlet was probably 600 feet wider three hundred years ago. Since the measurement is to an inlet, and inlets won't stay put, it could at times have been longer or shorter as storms changed the shape of the beaches. The retreat of the Jersey coast north of Bay Head has not been so great as the average of two feet per year for the offshore bar to the south. The 36½-mile-width of the State from Bordentown eastward to the seashore was only slightly greater when New Jersey became a state.

There has been no change in the distance across the narrowest part of the state from Trenton to Great Beds lighthouse in Raritan Bay, 33½ miles east of Trenton. For all practical purposes we can assume that New Jersey has an area of 8304 (7836) square miles and was less than one per cent larger when the first grants were made to John, Lord Berkeley and Sir George Carteret. In the next thousand years it should shrink a little more.

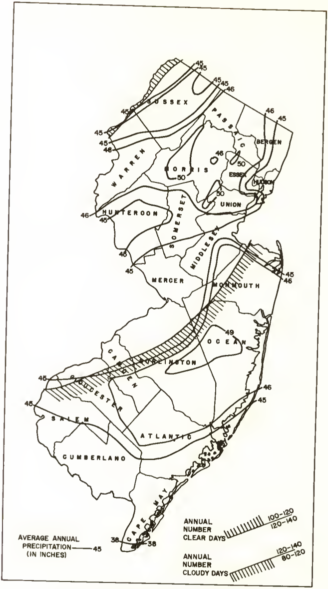
Like its geology, topography, and physical dimensions, New Jersey's weather and climate have changed only slightly since the explorers first called on the natives.

A compilation of very early references to weather indicates that a period of nearly one hundred years characterized by deep snow, extremely cold winters, and the Delaware River's being choked with ice, began about 1680. Like our variations in weather, there were occasional warm winters during the period. This time of extreme cold is sometimes referred to, by those who study Pleistocene events, as the "little ice age." During this same time of bitterly cold winters there were numerous references to very hot summers.

Actually the Weather Bureau statistics do not extend far enough back in our history to indicate any significant change in our climate. On the other hand, our knowledge of meteorology is becoming much more complete and there are the relatively new concepts of microclimates and urban weather. The new weather concepts and our technological ability will influence decision-making in respect to future land utilization.

The details of the average and maximum and minimum rainfall by month, by season, and by year can be obtained from most standard reference works. An examination of rainfall records from 400 locations throughout the world indicate that New Jersey's rainfall is unusual because of its reliability as to quantity and because of its even distribution throughout the year.

In northern New Jersey there is an average of 46 inches of rainfall per year. Several sections of the Highlands receive about 50 inches. Precipitation increases



MAP OF CLEAR AND CLOUDY DAYS AND PRECIPITATION

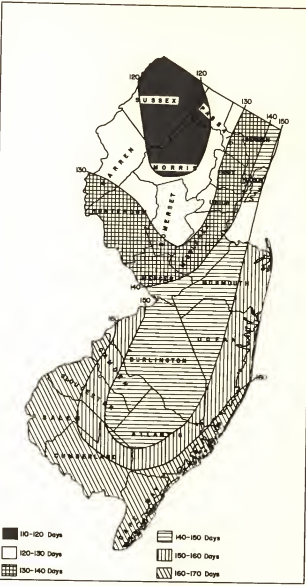
slightly during the late summer because of the intense thunderstorm activity. Much of the winter precipitation is in the form of snow.

In southern New Jersey there is an average of 45 inches of rainfall. Southwest of Toms River, in the general area of the Wharton Tract, the average rainfall is 48 to 49 inches. Cape May Point has the lowest average rainfall in the state with only 38 inches. Very little of the precipitation is in the form of snow in Cape May, Cumberland, and Atlantic counties.

The intensity of the rainfall and occasionally the amount of snow in a single storm is notably high when New Jersey is compared to other areas of North America. The state is favorably located both in winter and summer with respect to the location of the stable air masses of the Bermuda High and the Labrador Low. New Jersey's temperatures have ranged from an all-time high at Flemington of 108° F. to an all-time low of minus 32° F. at Layton. The recurrent average extremes of temperature vary from the 22° to 39° range in January up to the 63° to 85° range in July. During the winters there is a difference in average temperatures of about 3° for each 70 miles between northern and southern New Jersey. The global difference in temperature is about 1° for each 70 miles of latitude. During the summer, however, this thermal gradient is about 1° for the entire state and, except for the summer bathers, everyone swelters on a hot day.

Fuller and more accurate weather data suggest that New Jersey's sea breeze, so necessary for our vacation industries, affects only the immediate coastal area. This in turn suggests that New Jersey has more of a continental than a maritime climate.

Information for weather forecasting is gathered throughout the world at the uniform height of 6 feet above the ground. About thirty years ago it was recognized that this information was quite different from the conditions which existed at the level of most food plants. Much of the development in the application of this



MAP OF GROWING SEASONS

The growing or frostless season, in four-fifths of the year, based on records covering from 20 to 59 years.

From the "Atlas of Americas Agriculture," 1918

weather information to agriculture has been carried out in New Jersey. Because of the high monetary value of our crops, it is worthwhile to give attention to micro-climates. There are small but highly significant changes in average temperatures and other weather factors in very small areas. In part these differences are due to topography and in part they are determined by the plant ecology. For example, it is now recognized that trees planted on hillside slopes may effectively block near-surface cool air movements down the hillside to the valley bottom. Such planting can be used to delay the occurrence of the first killing frost and thus prolong the growing season in the valley.

It has also been proved with respect to New Jersey's specialized crops that maximum yield can be secured by careful attention to the amount of rainfall, sunshine, humidity, and other micro-climate variations for each particular farm or large field. Such close attention to these extremely small variations in local weather and climate permit the harvesting of each field or orchard at the height of its productivity.

One of the best examples of modern man's efforts to do something about the weather is the widespread purchase of portable irrigation systems in order to be able to supply water to a number of produce crops during the last ten days of the ripening period. With adequate water available to the plant roots at the right time, it is possible to harvest a higher grade fruit or vegetable and thus receive a higher price. Even though the irrigation systems may be used only once a year, and not necessarily in every year, artificial rain at the right time can pay big dividends.

The unusual character of urban weather has only recently been recognized. The intensely urbanized areas of New Jersey may have reached a size sufficient to have a measurable effect upon the local weather. The large number of surfaces radiating the sun's heat cause an increase in temperature. Evapo-transpiration is cut to a minimum because of the lack of vegetation, while run-

off is augmented by storm sewers and paved streets. Smoke, smog, and other forms of air pollution establish a dust lid over cities. Many tall buildings are obstacles to the free movement of the wind. The warm stagnant air, the dust lid, all cause markedly different weather conditions in urban areas.

In the south the growing season starts three weeks sooner and lasts approximately five weeks longer. A comparison of reports on the climate may lead to confusion because older reports give the growing season as the number of days between the last average killing frost in the spring and the first killing frost in the fall. Newer reports express the growing season as the number of days during which the average temperature may be expected to be above the critical dormancy temperature of 43° F. The difference between the frostless season and the growing season is about 40 days in the vicinity of Cape May and as high as 80 to 85 days in northern Sussex County. The difference in the two methods indicates the length of the farmer's period of worry. A farmer in southern New Jersey has a two to three week period of uncertainty in the spring and fall. The farmer in northern New Jersey must worry whether his crop will be ruined by a killing frost for five or more weeks.

The earliest Colonial census in 1726 showed a population of 32,000. By 1790 immigration and numerous offspring of colonial families had raised New Jersey's population to over 184,000. The annual rate of increase of the population during the 1726-1790 period, from 37 to 42 per 1000, has only been approached twice since, in 1910 and again in 1950.

Land utilization during the Colonial period was governed by the naturally favorable climate and soil conditions. Attempts may have been made during this and the subsequent period of land development to move into the less favorable terrains of the empty areas. Efforts to farm the pine barrens or to work the rocky slopes of the northern ridges were soon abandoned. The net effect of

topography, soil, and climate upon agricultural settlement was the development of towns from Cape May northward along the shore of Delaware Bay and for a distance of 10 or 15 miles inland from the Delaware River. The red shale valleys of the Piedmont or Triassic lowland were rapidly occupied as were northern Monmouth and Burlington counties. The steep slopes of the Palisades and the dearth of harbors on the Atlantic Coast prevented settlement along these shores for many years. Settlements, such as Hope, Wallpack, and others, developed in the limestone valleys on both sides of Kittatinny Ridge and between the ridges of the Highlands.

Occupation of the land was more and more governed by the non-agricultural resource factors as the agricultural society of Colonial times began to become self-sustaining and less dependent upon imports from Europe. Towns began to develop in the vicinity of water supplies and mineral resources. The first iron furnaces were associated with the limonite bog irons of the Coastal Plain. The Dutch efforts to recover copper had proved unsuccessful, but the English colonists began to extract copper in the Triassic Piedmont and iron from the Highlands. Roads were developed to the various furnaces and to the major water power sites.

Toward the end of this period, furnaces and forges in the Coastal Plain began to fail as the "mountain ores" being worked in the Highlands became more profitable. The beginnings of the industrialization which was to come were established at Trenton, Paterson, High Bridge, and Morristown because they were on transport routes and had abundant water power and water supplies.

The network of roads which had developed and the combination of sailing packets and stage coaches established New Jersey as the "Corridor State" by the end of the American Revolution. During the Revolution, the roads from Kingston and Newburgh on the Hudson, through the Great Valley and northwest of the Watchung Mountains to the vicinity of Easton and Phillipsburg at

the western edge of the State were used by the colonists to by-pass the British blockade of coastal shipping at New York and Philadelphia.

The development of canals and then, after 1831, of railroads had a profound effect upon the distribution of New Jersey's people. It became less important for farm and factory to be adjacent to natural means of water transportation in order to reach the major city markets. Manufacturing and quarrying began to develop along the Delaware above Trenton. The Morris Canal, and a little later the railroads, which served the area, caused a marked population growth from Morristown through Boonton, Dover, and Lake Hopatcong, to the Delaware near Easton. Many additional iron mines were opened in the Highlands, new factories and forges were built, and more farms to feed the growing cities were cleared along the Highland valleys.

An ambitious railroad project to bisect the Coastal Plain between lower New York Bay and Delaware Bay was undertaken after the Civil War. Of the many future cities, such as Vineland, Fruitland, and Wheatland, only the first, located in an area of naturally productive soils, fulfilled the promoter's dream. The reduced cost of transportation could not compensate for the lack of soil fertility. The farmers could not ship what they could not grow.

Railroads from Philadelphia to the seashore, and from New York to the Poconos and Catskills, hauled coal, foodstuffs, and lumber to the cities and developed an extensive traffic of city folk bound for a cooler summer vacation in the country. The southern New Jersey seashore towns began to receive vacation hordes when the railroad cut the travel time between Philadelphia and Cape May from two days to a few hours.

As the network of railroads grew in the century of industrial expansion, farms became larger, and farming, to supply the growing coastal cities with milk, fresh fruit, and vegetables, became an increasingly important segment of the economy. Until the development of the

BATSTO

Batsto is one of the Colonial "bog iron" centers. The lake provided water power for the iron foundry. The "bog iron" was extracted from the surface of the bogs (areas of dark vegetation in the background). Note the flatness of the Coastal Plain and the seemingly endless extent of the pine barrens whose forests provided the necessary charcoal.

New Jersey Department Conservation and Economic Development

railroad and refrigerated transportation, cattle were driven on the hoof to the city and fresh fruits and vegetables could be shipped only a short distance. As this shipping distance increased, more land was opened to agriculture. Farm acreage reached a peak in 1879 with nearly half of New Jersey's land area, over three thousand square miles, devoted to agriculture. In the following decades, food stuffs were supplied from ever increasing distances and New Jersey's farm acreage declined. Some Sussex and Warren county areas have returned to woods. In Cumberland and Salem counties and in the Hackensack Meadows impoundments returned to salt marsh.

Between 1900 and 1920 the soil characteristics were mapped for all of New Jersey's surface. These maps were based upon the character of the soil components, and the relative thickness of the three horizons in the soil profile to a depth of only three feet. This information was invaluable to the farmers at that time, and some of the maps are still being sold today. It was recognized about 1930 that these soil maps did not give a true picture since slope, wetness, permeability, and other factors which determine fertility had not been shown.

Under the old classification, names for 172 different soils types were developed for New Jersey. These were reduced in the newer classification to 28 major types with sub-classifications reflecting variations in slope or drainage. The modern soils map bears a remarkable resemblance to the geologic map. There are major differences between the glaciated and unglaciated portion of the State, and in the Coastal Plain where the yellow gravel complex of Pleistocene sediments has more of an effect upon the type of soils than do the underlying Tertiary and Cretaceous formations.

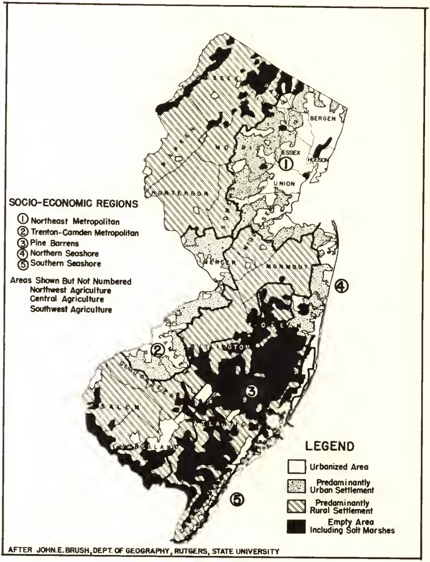
Between World War I and the 1930's land values rose as the needs of the increasing urban population required more space. Many acres of New Jersey farmland could no longer be profitably maintained. To stay in business the farmers had to improve soil fertility, adapt more

efficient methods, and work larger agricultural units. During this period, while farm acreage decreased, the number of agricultural workers per square mile continued to rise, as more and more farming was devoted to high-value truck crops. As fruit and vegetable strains were improved, even the cranberry and blueberry of the pine barrens were cultivated and became cash crops, like peaches, tomatoes, or asparagus. Nurseries for flowers, ornamental shrubs, and trees needed for growing suburbia occupied more and more land formerly devoted to food crops.

The general land-use patterns for the State as we knew them had been established by 1930, the beginning of the Modern Period. The development of the automobile as a practical medium of transportation, the development of commercial airlines, of electric power, and natural gas transmission lines, and the sociological changes resultant from a shorter work-week and higher annual incomes have caused a radical change in land-use needs.

The axiom that people attract people remains unchanged, but the metropolitan area now has a greater radius. The space required by the city dwellers has increased as individuals have used their newly acquired mobility to move from apartment buildings to their own houses in the suburban fringe. As highway systems have grown, industry has been less dependent on railroad lines and less restricted by terrain. Factories can now be built in the country, utilizing the local farm population for a labor force. One of the new industrial parks has been established on a wooded ridge of the Highlands. This change in country living produces the rather odd statistical picture of less farming with more people in the countryside.

Increased leisure time and greater mobility have developed new recreational needs since World War II. The boat on a trailer, the camp outfit, the jeep, and the outboard motor boat are opening many empty and almost useless areas of our State not only to many new



DISTRIBUTION OF NEW JERSEY POPULATION
After John E. Brush, Department of Geography, Rutgers University

kinds of recreation, but also to suburban living in the amphibious lagoon developments cut from salt marshes, or exclusive forest-lake complexes in the Highlands.

Forty-fifth in size, about eighth in population, New Jersey in 1960, with a population of 6,066,782, became the most densely populated state in the Union. The average population density of 807 people per square mile is misleading because slightly more than one-fifth of the land area is unoccupied. Sussex County has a density of 93 people per square mile, and Warren, because of the 5000 people per square mile at Phillipsburg and four other towns with a density over 1000 has 175 people per square mile. Hudson County has a population of 13,572 per square mile in spite of a loss of over 5 per cent of its residents in the last decade. West New York, a town in Hudson County with 35,547 people crowded into nine-tenths of a square mile, is New Jersey's most densely populated area. Pahaquarry Township in Warren County with 63 people in its twenty-plus square miles along Kittatinny Ridge, has the most open space.

Only about 2 per cent of New Jersey's citizens are actually farmers. Most of the people living in rural areas are classed as non-farming population. As defined by the 1950 census, in which six counties were classed as rural, the actual farm population would provide a density of 86 persons per square mile.

In contrast to the empty areas of Kittatinny Ridge, the 1462 square miles of the pine barrens, the three swamps of the Great Swamp Complex in Morris County, and the Hackensack Meadows at the back door of Hoboken's 40,000 citizens, there are six cities of over 100,000 population and eight more of over 50,000 in New Jersey. About 78 per cent of New Jersey's population lives within 30 miles of New York City, within 20 miles of Camden, or within 10 miles of Trenton or Atlantic City.

The census and population density figures indicate where people live. The daytime concentration of the

work force, which causes Newark's population to reach nearly a million, and the seasonal movement of tourists and vacationers, which may double the population of the resort towns, are not shown in the normal population statistics.

From Indian times until well into the Industrial Period, topography and soil fertility guided population density and land-use patterns. Man's greater knowledge, improved technology, increased mobility, and changing desires are obliterating these old patterns of geography. New Jersey's limited space is being consumed by an increasing population which is no longer content to live, work, and play in its crowded local neighborhood.

X

GEOGRAPHY AND GEOLOGY

IN THE PRECEDING CHAPTERS we have seen how New Jersey today is the end product of millions of years of geologic events. The same processes, the same methods of reasoning may be applied to geologic speculation—without fear of contradiction because none of us or our children's children's children will be around to check up on the predictions—as to what New Jersey will be like in the millennia to come. What man may do in the immediate future is more difficult to predict. We can be sure that the geologic changes will continue in spite of jet ports, Green Acres, and the building of Megalopolis.

We have learned how the New Jersey of today is composed of four general regions or physiographic provinces (the Highlands, the Ridge and Valley, the Triassic Piedmont, and the Coastal Plain) each with its distinct geologic history, topography, and geographic characteristics.

The ancient rocks of the Highlands, because of their hardness, mass, and location with respect to drainage will remain the barrier to transportation and development that they have been since earliest Colonial times. The great future city, Megalopolis, may grow across the narrow mountain ridge of the Highlands of northern Hunterdon as Phillipsburg, Easton, Bethlehem, and Allentown join the future metropolitan areas of Clinton, Flemington, and Somerville. The bulk of the Highlands and perhaps also the Hunterdon Plateau and its Penn-

sylvania extension will remain centers of recreation and open space. The numerous sites for water power and water storage will be utilized as the region grows and will, as they do now, augment the recreation capability of the area.

It is conceivable that, in spite of zoning and urbanization, iron, copper, rare earths, uranium, cement rock, and the always necessary traprock will continue to be worked or will be worked from old or even yet-undiscovered localities as the need for these new materials is less and less economically met by alternate foreign and distant sources or substitute materials. The zinc mine at Ogdensburg will eventually be exhausted just as Franklin was a few years ago. The peat moss will be eroded away or used in place as it is now used for truck farming, or we may even see a revival of the peat-mining industry and its shipment to the garden centers of suburbia. The more isolated, rugged, and wooded areas of the northern ridges of the Highlands will gradually become centers of recreation, research centers, or expensive plots for country houses. Because of the rugged terrain, the Highlands will continue to channel the development of Megalopolis into the areas to the south and east.

All that has happened and will happen in this area is the result of the crustal movements of the Appalachian revolution from about 400 million to 200 million years ago. The roots of the ancient mountains were raised to a level where erosion, which had, of course, reduced the area to a peneplain, could etch out the present topography in the last 70 million years as the fall-zone peneplain and then the Schooley peneplain were raised and tilted in Cretaceous and Tertiary times. The Pleistocene glaciations have slightly modified the terrain of the northern half of the Highlands. In the span of geologic time, the lakes will quickly fill to become bogs and the glacial deposits will almost as quickly be removed from the bedrock surface as the streams and rivers reorganize the drainage pattern.

The northern part of the most rugged topography of

New Jersey—the Ridge and Valley Province—will continue to be a corridor between the upper Hudson Valley and the Easton-Bethlehem-Allentown complex. The construction of the Tocks Island Dam will convert the entire area north of Kittatinny Mountain into the largest and most accessible recreation area in the northeastern United States. This engineering project will probably cause a population growth in the area in relation to the rest of the state not experienced since the Dutch built the old mine road in the 1650's.

The durable quartzite of Kittatinny Ridge will persist like the gneisses of the Highlands. The limestone valleys will become lower as will the shales, but at a much slower rate. Perhaps a few thousand years from now some of the small limestone caves will develop into commercial caverns of great beauty. As part of the process of stream erosion in New Jersey, the falls at Paterson may eventually be found in the Caldwells, the students at the School of Conservation in Stokes Forest will be able to walk a few hundred yards to the head of Tillmans Ravine instead of riding several miles, as they must at present, to view the water falls in the gorge.

Since the oldest fifth of the state, the Highlands and the Ridge and Valley Province, are already the roots of a long vanished mountain system, their disappearance from the Jersey scene will be slow.

Very similar to the Highlands in its past geologic history, the Ridge and Valley area will have a similar future. Although the rocks are not so hard, most of the formations have already been eroded to within a few hundred feet of sea level and even closer to the base level of erosion below which streams cannot remove material that is not in solution. The so-called Harrisburg and Somerville peneplains, the present flat-bottomed valley terrace levels, will continue to develop. As in the Highlands, lakes and glacial deposits will be the first land forms to disappear.

The Triassic lowlands of the Piedmont Physiographic Province are the most densely populated part of our State.

This topography started developing from the Schooley peneplain at the beginning of the Tertiary Period, about 70 million years ago. During the preceeding 200 million years of the Triassic; sandstones, shales, argillite lake deposits, and basalt lava flows of the ancient New Jersey rift valley had been deposited, peneplained, and then buried under several hundred feet of Cretaceous sands, clays and marls. Today's topography will be accentuated but not radically changed.

The most densely populated part of the State since Colonial times, the site of the earliest industrial development, the site of the first railroads and canals; the area is well on its way, together with the so-called Inner Coastal Plain, toward fulfilling its destiny as Megalopolis. Whether the area of Hunterdon, Mercer, Somerset, Middlesex, and western Monmouth counties will become another complex of suburbs like the present area from New Brunswick to Paramus or will become a hole in a Megalopolis doughnut will depend a great deal on the action of local government officials in the next few years. The area has always been and will remain the low-level corridor between several of the world's largest cities. Since people attract people, the problems of water supply, sewage disposal, open space, and conflicting land uses will rapidly snowball into a condition which will almost defy solution. The population density will probably require water resource support from other areas in the State and even from beyond our borders.

The Coastal Plain three-fifths of our State is the geologically youngest, softest, and least resistant to erosion, and topographically the flattest and lowest area in the state. It will therefore undergo the greatest change in geography and geology in the shortest time. Geographically the Inner Coastal Plain is part of Megalopolis. Without internal topographic barriers, such as the Watchungs, the Sourland Mountains, or the Hunterdon Plateau and no southeastern border, the extent of growth will depend on the development of transportation routes to augment the present corridor on either side of the

Delaware River. At present Delaware Bay is like a dagger in the heart of the industrial development of southern New Jersey. A mid-Delaware-Bay bridge and a Cape May–Lower Delaware bridge-tunnel would seem to await only the will to make the investment in the initial cost. Changes in the geography of the Coastal Plain, more than anywhere else in the state, will depend on man and his engineering and economic development efforts.

Apple Pie Hill, Arney's Mount, and the cuesta of late Cretaceous sediments, Atlantic Highlands, and the gravel-capped Beacon Hill will all disappear a bit faster than the hard basalt of the Watchungs or the granite gneisses of the Highlands. An infinitesimal bit of this destruction will be helped along by man as New Jersey's more than 125 sand pits continue for years to produce sand and gravel as our leading mineral commodity. The construction of McGuire Air Force Base and the facilities of Fort Dix and Lakehurst Naval Air Station have already taken much of the gravel off the tops of Coastal Plain ridges so that in Monmouth, Ocean, and Middlesex counties a new inversion of topography may be speeded on its way.

The Raritan and lower New York Bay, the lower Delaware River and Delaware Bay will be filled in as the everlasting mountains are worn away. If nothing intervenes the present dominance of stream erosion graded to the present or a higher sea level could conceivably fill our major river valleys until the Raritan again runs up the Millstone and down the Metedeconk, and the Delaware runs up Crosswicks Creek and down the Wading or Toms River. Perhaps the Hudson will again flow southwest across a broad flat valley as it apparently did a few hundred thousand years ago in Pennsauken times. The flooding of rivers and streams has probably been observed by everyone but the geologic changes caused at such times are so slight as to go almost unnoticed. However, each flood does its bit to add to the cumulative effect of stream erosion which in geo-

logic time moves great volumes of material from high to lower ground.

Eventually whether this happens or not, ice may again stand upon New Jersey. We are still coming out of (warming up from) the Wisconsin glaciation. World geologic conditions are such that if the Ice Ages concept is accepted, we can reasonably expect a return engagement with the continental glaciers in a few tens of thousands years. Before the growing ice cap diverts the St. Lawrence down the Hudson Valley and moves our seashore far to the east, we can expect a greater submergence of New Jersey. Perhaps the rising sea level will develop the two islands east of Trenton and south of Philadelphia. On the other hand, as mentioned above, the deposition of sediments may keep pace with the submergence of the Coastal Plain or even fill in our present valleys faster than the water rises. If we could live ten thousand years, and sea level stayed the same or rose at its present slow rate, we could walk the beach of Long Beach Island without bucking the weekend traffic jam on the bridge across the bay because the beach would be against the mainland shore only a stone's throw from the Garden State Parkway.

Although the most easily observed geologic changes occur during periods of storm and rainy weather, even disastrous floods or coastal storms seemingly cause little except local damage. Damage, sufficient to overwhelm the property owner affected, from the over-all view is almost insignificant. Vulcanism, a geologic process with occasional spectacular results, has not occurred in New Jersey since Triassic (possible Jurassic at the latest) times. Earthquakes, which often cause severe destruction and great loss of life, less often visibly change the topography. There have been 14 earthquakes in New Jersey in historic time. All have been slight. Probably no major earthquake has occurred here since Cretaceous times.

It is coastal erosion, along a sandy coast like New Jersey's, which most rapidly changes the landscape over

wide areas. It is to this geologic process that we in New Jersey must look for evidence of geology at work. However, the life of man whether he be a shore fisherman, a boating enthusiast, or just a lover of sand, sun, and surf is so short and the major storms so many years apart that, except for minor changes about inlets or about shore-protection works, we do not see any great natural change in the beach during our lifetime.

The lifetime of any man is but a geologic snap of the fingers.

BIBLIOGRAPHICAL NOTES

In 1946, a Bibliography and Index of the Geology of New Jersey compiled by Agnes B. Grametbaur was published as *Bulletin 59* of the New Jersey Geological Survey. This bulletin lists about 1800 books, papers, and reports on New Jersey Geology by over 600 authors. No less than 270 of these references were the work of the five state geologists who have held office between 1836 and 1958.

Bulletin 59 and *Bulletin 50*, "The Geology of New Jersey" have long been out of print but together they provide a complete reference to the geology of New Jersey up to 1946.

The Geological Society of America's, *Guidebook for Field Trips*, (Atlantic City Meeting 1957), edited by Erling Dorf provides an excellent summary of the major changes in geologic concepts since the publication of the 1940 revision of *Bulletin 50* by H. B. Kummel.

The Bureau of Geology and Topography in the Division of Resource Development of the Department of Conservation and Economic Development, or as it is perhaps more commonly known, the New Jersey Geological Survey, has produced 133 publications since the first progress report was issued by the first State Geologist, George H. Cook. Cook issued five progress reports and then completed the first *Geology of New Jersey* and the first geologic map of the state in 1868. Thirty-nine annual reports were issued from 1870 to 1910, at which time a bulletin series was started for the publication of the results of the many activities of the State Geological Sur-

vey. In addition to geology, these 65 bulletins covered geodetic control monuments, soil maps, and such diverse subjects as forests, flora, archeology and the application of geology to engineering works.

Eight reports, entitled the Final Report of the State Geologist, were issued in the 29 years from 1888 to 1917. Toward the end of this period, four reports were also issued on paleontology. These twelve volumes summarized the geologic and geographic knowledge of New Jersey at the time. Their contents were neither final nor encyclopedic compilations of their subjects, but they are still most useful as reference material giving the details of the geology and geography of New Jersey.

Beginning in 1959 a geologic report series was started for those items which contained detailed technical information about the work of the Bureau of Geology but which would not merit publication as bulletins because of their limited interests.

Where appropriate, unpublished manuscripts in the Bureau files, and information from the file of permanent geologic notes were drawn upon in the preparation of this volume.

In addition to the publications of the State Geological Survey, there are numerous short papers by geologists working for other agencies on geological problems in the State. The publications of the United States Geological Survey and of the United States Bureau of Mines, contributions to professional journals by geologists at Rutgers, Princeton, the Philadelphia Academy of Science, and many other educational institutions located in bordering states are essential for complete information on specific geologic topics.

Publications of the State Department of Agriculture, other State Departments, other Divisions of the Department of Conservation and Economic Development, and of other Bureaus within the Division of Resource Development provide information on a variety of specialized subjects—soils, weather, land use, water supply, commerce, and industry.

Bulletin 50 and the Geological Society of America *Guidebook for Field Trips* (Atlantic City Meeting, 1957) were used freely as guides in the preparation of each geologic chapter. Recent papers and older reports were used for specific details.

In the preparation of the geography chapter and of the physiographic information in the other chapters, a great deal of material was obtained from Vol. I, Report of the State Geologist, *Circular 601* of the U. S. Soil Conservation Service, bulletins of the New Jersey Geological Survey and research reports of the Bureau of Commerce in the Division of Resource Development.

The Population of New Jersey, by John E. Brush (New Brunswick, 1956), provides a very complete summary of population statistics, population density and land use. Any study of the geography of New Jersey must include *Megalopolis,* by Jean Gottmann (Norwood, Massachusetts, 1961). A report on *The Economy of New Jersey* (New Brunswick, 1958) prepared by Rutgers scholars under the direction of Professor S. J. Flink has several interesting chapters.

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THE NEW JERSEY HISTORICAL SERIES

Published Under the Auspices of

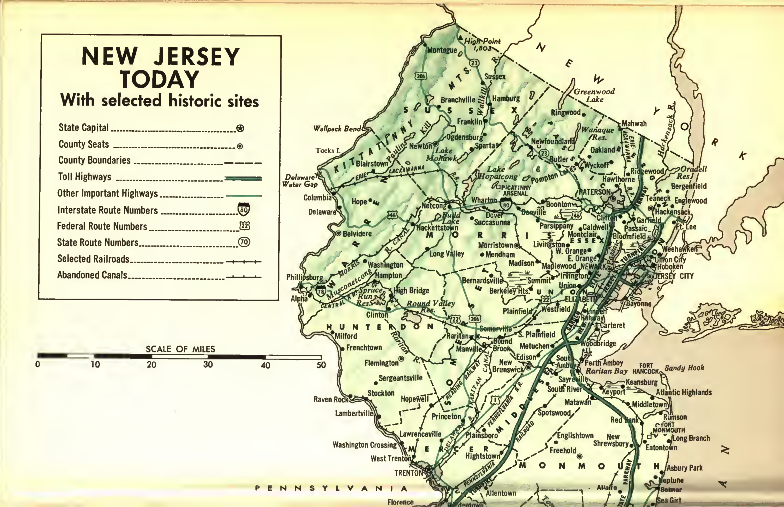
STATE OF NEW JERSEY TERCENTENARY COMMISSION

TABLE OF GEOLOGIC AGES

Geologic time intervals are arbitrary divisions of unequal length. Each may be matched by one or more geologic formations. An Era, the largest division of geologic time, is subdivided into smaller units called Periods. Formations, which are mapable rock units with distinctive lithology, may be assigned to Periods or smaller subdivisions of geologic time on the basis of distinctive fossils if present. The fourth column below indicates the total millions of years before the present when each geologic period began.

Era	*Period*	*Epoch*	*Time in Millions of Years*	*Rock Types and Location*
Cenozoic	Quaternary	Recent	1/10	Present-day stream deposits: beaches, etc.
		Pleistocene (Ice Ages)	1	Glacial deposits in north: yellow gravels in central and south
	Tertiary	Pliocene Miocene Eocene Paleocene	70	Unconsolidated sediments of the New Jersey Coastal Plain: southern part of all of counties south of Trenton and New Brunswick
Mesozoic	Cretaceous		135	Unconsolidated sediments of the northwestern part of the Coastal Plain in southern Mercer and Middlesex counties and northern Monmouth, Burlington, Camden, Gloucester, and Salem
	Jurassic		180	Not found in New Jersey

	Triassic	225	Red shales, sandstones, argillites, basalt lava flows, and diabase intrusions of the Piedmont Province: northern Mercer and Middlesex counties, southern Morris, central and southern Hunterdon, nearly all of Somerset and Bergen, and all of Union, Essex, and Hudson counties
Paleozoic	Permian	270	Not found in New Jersey
	Pennsylvanian Mississippian	350	Not found in New Jersey: Pocono Plateau of Pennsylvania
	Devonian	400	Limestone of the Upper Delaware: northern Sussex County. Conglomerates: Bearfort Mountain area of Passaic and Morris counties
	Silurian	440	Conglomerate and sandstone: northern Warren and Sussex and shales and conglomerates in the Green Pond Valley of Morris and Passaic
	Ordovician	500	Shales and limestones of northern Sussex and Warren counties, also Clinton, Peapack and other small areas south of Highlands
	Cambrian	600	Limestone and sandstone: Sussex and Warren counties, Trenton area
	Precambrian	(?)	Metamorphic rocks and Franklin marble of the Highlands: northern Hunterdon, Morris, Passaic, and southern Warren and Sussex counties; Trenton area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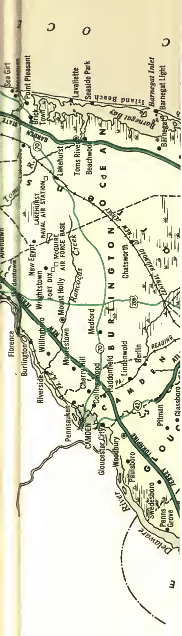

(Continued from front flap)

vances and retreats of the Cretaceous and Tertiary seas.

Although much has happened since then, the million years just past has been witness to one of nature's most awesome phenomenon—the great Ice Caps of the Pleistocene. The author discusses this continental glaciation, and explains how such tremendous forces reshaped the state into the form in which we know it today. He has also been able to project these geologic "laws" and show us a picture of New Jersey in times to come, millions of years in the future.

Few areas in the world can equal New Jersey in its geologic complexity and variety and in its resulting contrasts in geography. It is necessary, therefore, that an accurate, readable account be made of how the "State of Contrasts" evolved. Dr. Widmer's book provides such an account.

KEMBLE WIDMER is State Geologist and Chief of the Bureau of Geology and Topography in the Department of Conservation and Economic Development. He has also been an Assistant Professor of Geology at Rutgers—The State University, and an Associate Professor and Chairman of the Department of Geology at Champlain College, of the State University of New York.

Dr. Widmer, a native of New York, received an A.B. in Geology from Lehigh University, and A.M. and Ph.D. degrees from Princeton University. He has also done graduate work in groundwater and economic geology at Stanford University.

For four summers he headed field parties for the Geological Survey of Newfoundland, and his investigations of the geology and mineral deposits of the Hermitage Bay area, Fortune Bay in Newfoundland, are to be published by the Canadian Geological Survey.

Jacket Illustration:
Delaware Water Gap.
Dotted line indicates faulting.

1736

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